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SOIL CONSERVATION SERVICE - RESEARCH

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In cooperation with the Colorado and Illinois Agricultural Experiment Stations

INFILTRATION IN RELATION TO RUNOFF ON SMALL WATERSHEDS

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SUMMARY

The need to estimate runoff from various watersheds and land areas is a continuing one that confronts many practicing hydrologists. Estimates made purely on a basis of the character of rainfall are rarely satisfactory. The problem essentially involves the amount of excess precipitation that occurs on different parts of the area where infiltration differs. It is complicated further by the fact that infiltration on the different parts of an area varies with seasons and with other factors. Furthermore, surface detention and retention provide at least temporary reductions in runoff and affect the peak rates at the outlets.

Studies were organized and established on claypan soils near Edwardsville, Ill., and on the more youthful and permeable soils in the vicinity of Colorado Springs, for the purpose of learning more about the relation of the various segments of a watershed to its performance as a whole.

On these watersheds information was obtained as to variations in soil and vegetal cover, and infiltration curves were derived for the various segments through repeated operations of an infiltrometer, including the sampling at frequent intervals of all parts of the watershed. These studies show significant relationships between infiltration, vegetal cover, and soil depths. At Edwardsville they also showed significant relationships with antecedent soil moisture, while at Colorado Springs they showed significant relationships with soil and water temperature.

The Type F infiltrometer which was used to sample the various segments of the watershed provided the basis for hydrographs of the different segments of the area and their deviation with season. On the basis of this and other information, isopotal areas, or areas having similar infiltration characteristics, were delineated.

On each of the isopotal areas semipermanent plots were installed so that rates of runoff on an exaggerated scale were obtained for the same natural storms that produced runoff from the entire watershed.

The basis was thus laid for various trials of computing runoffs and comparing them with actual runoff from the entire watershed.

On the claypan watersheds at Edwardsville it was found that the infiltration varied with soil moisture content, depth of soil, and to some extent with the nature of the vegetal cover. The infiltration varied seasonally with the maximum occurring in midsummer. For a number of large storms the computed hydrograph agreed very closely with the observed hydrograph.

The synthetic hydrographs were derived by: (a) computing the excess water of the storm for each isopotal area; (b) routing this excess water through the incised channels of these watersheds, with proper allowance for storage en route; and (c) computing by units of time the volume of water arriving at the outlet.

For storms of low intensity, however, greater difficulty was found in achieving agreement, due probably to wider variations in canopy interception, surface detention, and infiltration in the freshly saturated soil zone.

On the more permeable soil at Colorado Springs, the conditions called for a somewhat different approach to the calculation of a synthetic hydrograph. On this watershed there were no incised drainageways but there was

a grassy swale leading to the weir, composed of highly permeable material in which the infiltration rate was very high. For small storms the yield of water from the margins of the basin would often be entirely infiltrated in the grassy swale. For large storms, however, where the infiltration was a small proportion of total water from the watershed, there were much more direct relations between the hydrographs of small plots within the watershed and the hydrograph of the complete watershed.

These studies have not been designed for the primary purpose of determining a quick method of predicting runoff. Instead, they have been designed to explore the hydrology of the various segments of the watershed and to determine insofar as possible their effect upon the composite whole. Although the period of record is short, and the number of storms occurring on the Colorado watershed in particular was small, it is believed the study discloses considerable information useful to hydrologists.

SUMMARY

The need to estimate runoff from various watersheds and land areas is a continuing one that confronts many practicing hydrologists. Estimates made purely on a basis of the character of rainfall are rarely satisfactory. The problem essentially involves the amount of excess precipitation that occurs on different parts of the area where infiltration differs. It is complicated further by the fact that infiltration on the different parts of an area varies with seasons and with other factors. Furthermore, surface detention and retention provide at least temporary reductions in runoff and affect the peak rates at the outlets.

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The composite effect of the several variables affecting infiltration on a watershed and its relation to runoff may be evaluated in a quantitative way by directly measuring the rainfall and runoff on sample areas by means of an infiltrometer, and subsequently computing infiltration from these measurements.

The development of the infiltration concept as a primary factor in the determination of surface runoff is a product largely of the last decade. Although references to it had been made as early as 1869 by George P. Marsh (7)[2] and some experimental work had been conducted by Ivan Houk (5) in 1916, little attempt at its quantitative evaluation in terms of runoff was made until much later. Qualitative recognition is found in the literature as early as the writings of Columella (1) in the first century A. D. From then until comparatively recent times the relatively few workers giving consideration to infiltration or "the absorption of rainfall by the soil" directed their attention mainly to the conditions which were believed to increase its magnitude. Little or no attempt was made to forecast the quantity of runoff from a known basis of rainfall and infiltration.

The urgent necessity of predicting runoff was apparent, however, on every occasion calling for designs for the control of runoff, whether these were for urban storm sewers, highway culverts, or agricultural lands and flood control. Thus, the use of a "coefficient of runoff" came into use on the fallacious assumption that an area of a given size yielded some more or less fixed percentage of the rainfall as runoff. This concept has its adherents owing largely to the scarcity of infiltration data and an inadequate understanding of infiltration phenomena. The following formula is often used: $Q = C I A$; where Q is the rate of runoff, C is a coefficient assumed to be characteristic of the watershed, I is the intensity of rainfall, and A is area in acres.

Many workers using this formula recognize the fact that no single coefficient can adequately express the widely variable conditions of a watershed, (4) but in the absence of suitable infiltration data they find that a coefficient provides some means, however inadequate, for making an estimate of runoff.

In the work of the Soil Conservation Service, wherein measures for the conservation of soil and water are being applied to the lands of the Nation, the need for estimating the expected quantities of runoff for numerous conditions on farm lands is no less urgent than for municipalities, highways, and railroads. The proper design of terrace systems and contour furrows, and an adequate interpretation of the effects of various land usages upon the rates of runoff and of erosion to be expected, provide continually recurring problems for which the best possible solution is needed.

The purpose of the experiments reported herein was to explore within the limits of available facilities some of the relations between rainfall, infiltration, and surface runoff on small relatively uniform watersheds. Given rainfall intensities and infiltration rates, to what extent can they be used to predict rates of discharge? What, if any, additional information is needed? In brief, can the runoff problem be broken down into its elements; and can the major elements be evaluated so as to give reasonably accurate estimates of runoff? An answer to these and related problems, even for a few relatively simple cases, if based upon reliable factual evidence, should have numerous practical uses.

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[1] Formerly Associate Agricultural Engineer in Research.

[2] The numbers in parentheses refer to Literature Cited, listed at end of publication.

DESCRIPTION OF EXPERIMENTS

The experiments may be briefly outlined as follows:

(1) Determination of the variations in a watershed with respect to the major physical factors affecting infiltration, such as soil depth, soil moisture, and plant cover.

(2) Delineation of areas having similar infiltration characteristics, based on the above factors, and testing this delineation by the infiltration actually obtained under natural rainfall conditions.

(3) Comparison of infiltration on the various parts of a watershed with that of the entire watershed.

(4) Computation of runoff by means of infiltration data for the parts of a water shed, and testing this computation by the use of measured watershed runoff data.

A thorough sampling of the watersheds revealed the infiltration characteristics of their various parts over a 24-month period and permitted the mapping of the characteristics of the soil and vegetal cover. The rainfall and runoff records for the entire watersheds over a period of years were analyzed.[3] Much supplementary data dealing with such environmental conditions as soil moisture, temperature, variations in land management were also obtained. Recording rain gages were suitably placed throughout the watersheds with an average spacing of at least 1 per 10 acres. During the later stages of the work, records were obtained simultaneously from plots and watersheds for each storm; the plots being of the same dimension as those of the type F infiltrometer used in the early sampling stage. On certain of the watersheds the depth of flow of water in the natural drainage ways was determined.

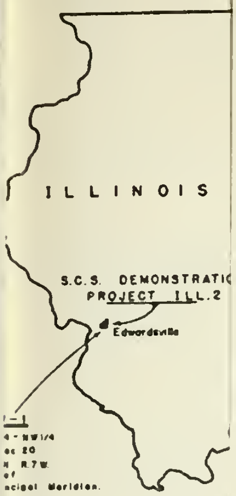
WATERSHEDS

The studies reported herein were performed on three small watersheds, two near Edwardsville, Ill. (designated E-I and E-II), and one near Colorado Springs, Colo. (hereinafter referred to as CS-III). These watersheds have been under observation and measurement by Hydrologic Studies, Soil Conservation Service Research, since 1938.

The 3 watersheds vary markedly in topography and other respects (figs. 1, 2, and 3, pp. 3, 4, and 5).

Watershed E-I, Edwardsville, Ill. (fig. 1), 27.2 acres in area, was in alfalfa. The center rectangular field had been in alfalfa about 2 years at the time these studies were started in 1940. The other two fields were in young alfalfa, seeded in 1939. The prevailing land slope is approximately 1 percent with a range in slope from 0.4 percent to 10 percent. The watershed is fan-shaped with three principal waterways. The steeper slopes border the waterways. The soils consist principally of two series: (1) Alma, on the steep land near the waterways; and (2) Bogota, on the flat land. The Alma soil is a silt loam in the A horizon, 7 inches in depth. The B horizon is a light reddish-yellow silty clay loam slightly compacted and rather impermeable. The Bogota silt loam on the flat slopes has an A horizon 16 inches in depth and varying from a dark yellowish-gray silt loam at the surface to a yellowish-gray floury silt loam in the A_3 horizon. The subsoil is a silty clay loam with granular structure in the B_1 horizon, and a medium compact and plastic silty clay loam of only fair permeability in the B_2 horizon.

[3]Acknowledgment is due D. B. Krimgold, H. K. Rouse, and Neal Minshall of the Section of Hydrologic Studies, Soil Conservation Service, for much of these and other records.



LOCATION MAP

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VIEW NEGATIV
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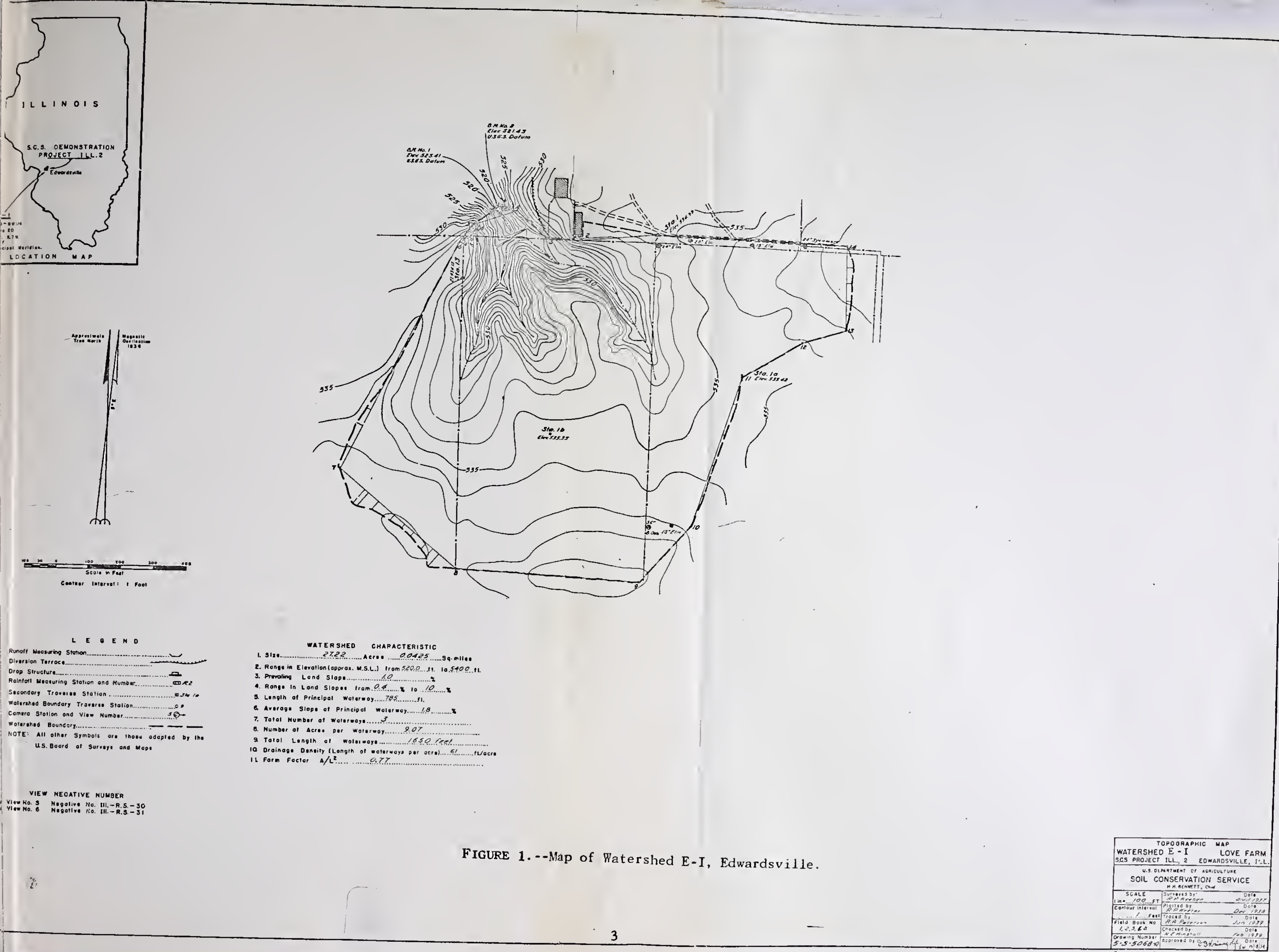
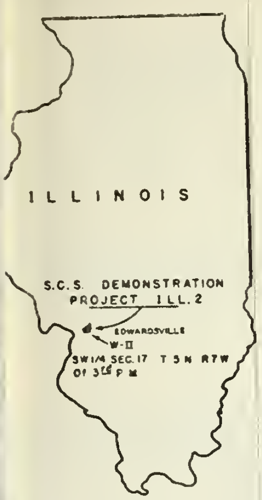
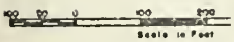


FIGURE 1.--Map of Watershed E-I, Edwardsville.



LOCATION MAP



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LEGEND

Rainfall Measuring Station and Number___
Runoff Measuring Station__________
Secondary Traverse Station_______
Watershed Boundary Traverse Station__
Camera Station & View No._______
Watershed Boundary__________
NOTE: All Other Symbols Are Those /
Board Of Surveys And Maps.

VIEW	NEGATIVE NUMBER
View No. 9	Negative No - Ill. - RS
View No. 10	Negative No - Ill. - RS
View No. 11	Negative No - Ill. - RS
View No. 12	Negative No - Ill. - RS

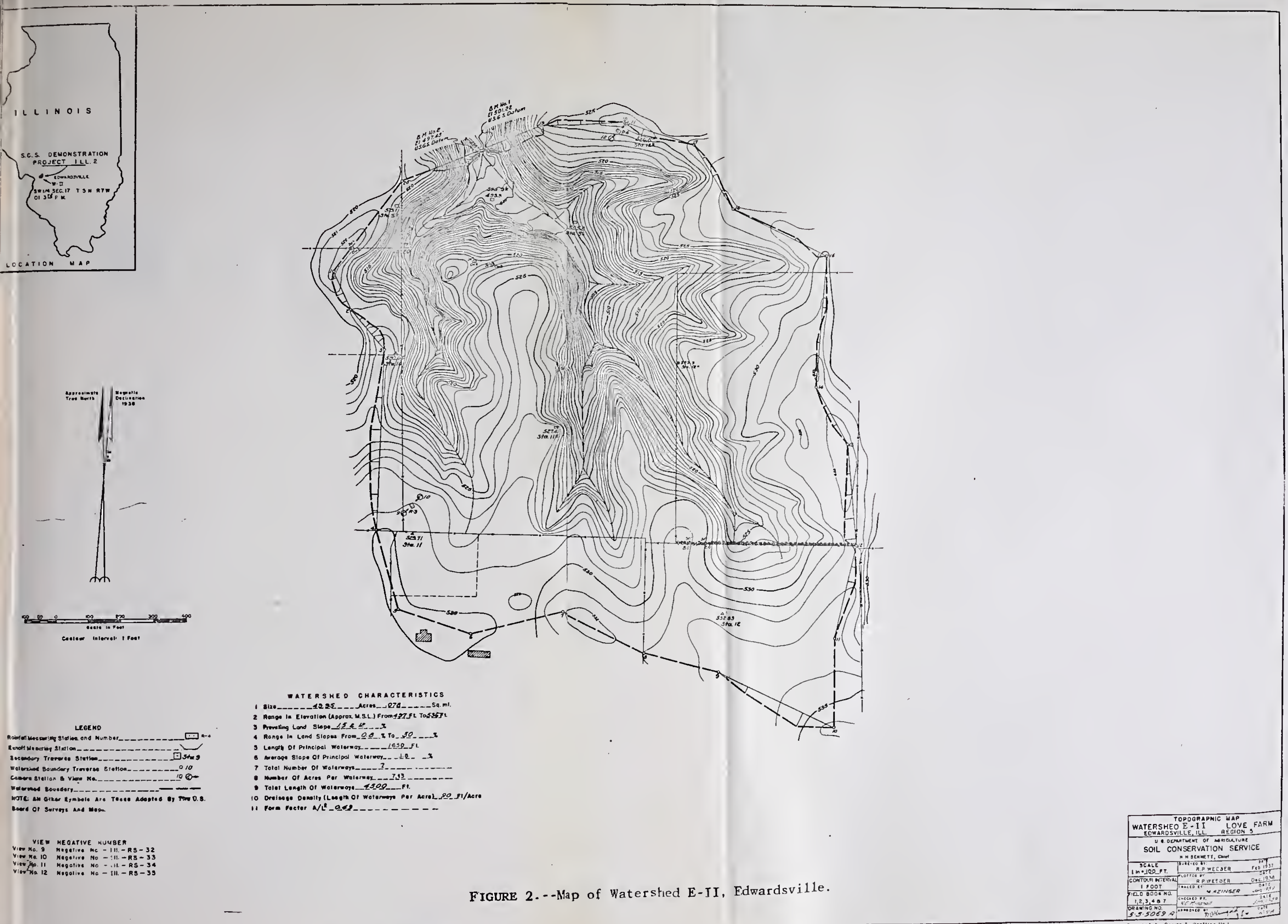
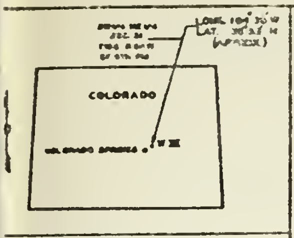
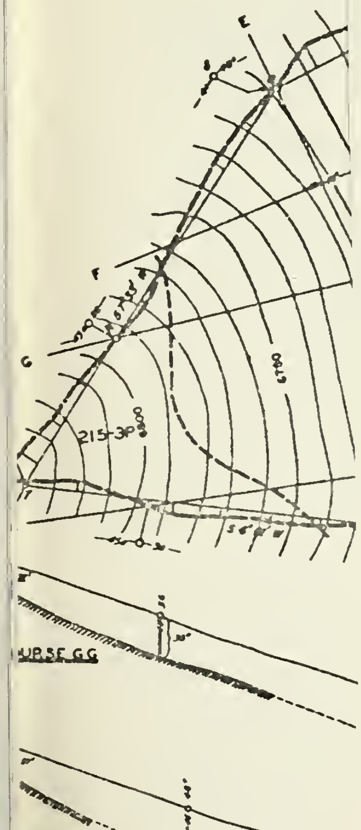


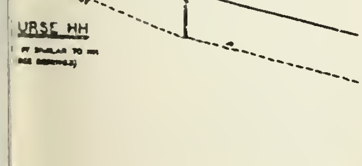
FIGURE 2.--Map of Watershed E-II, Edwardsville.



LOCATION MAP

...L	TYPE	ACRES	% OF AREA	
[illegible]	UNCLASSIFIED	[illegible]	[illegible]	[illegible]
[illegible]		4.14	18	[illegible]
[illegible]		[illegible]	1	[illegible]
		[illegible]	[illegible]	[illegible]





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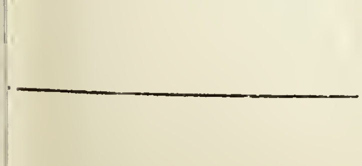


...URSE HH

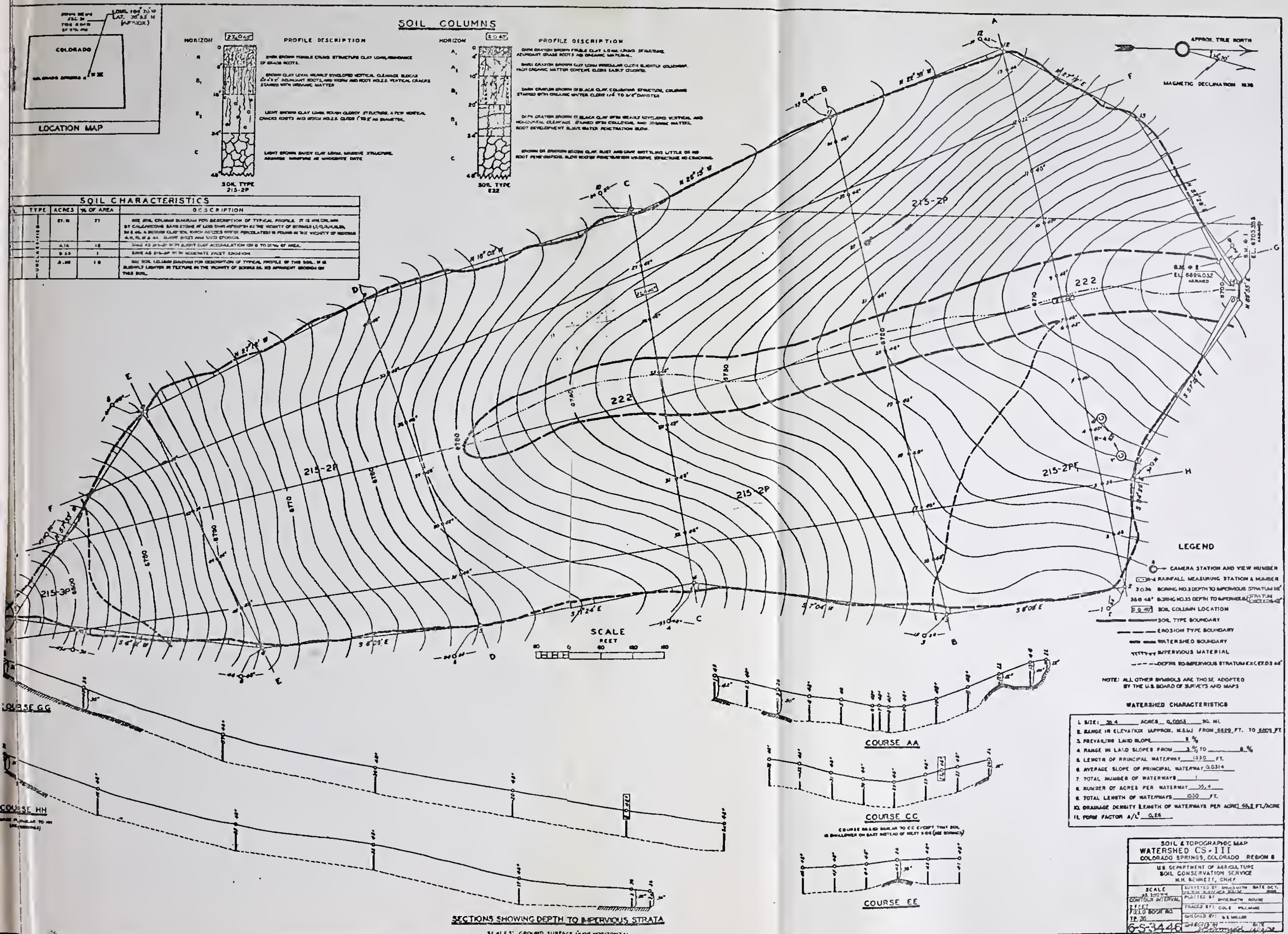


FIGURE 3.--Map of Watershed CS-III, Colorado Springs.

Watershed E-II (fig. 2, p. 4) is roughly square in shape, 49.9 acres in area, and fairly well dissected with waterways, which extend well up nearly to the rim of the watershed. Slopes range from 0.8 to 30 percent with prevailing slopes of 1.5 and 12 percent. Soils are Bogota, Alma, Elco, and Drury, from top to bottom. The three former are silt loams and the last a very fine sandy loam. The distribution of these soils is shown in figure 4, page 7. This watershed is used as a pasture. Cover conditions were quite varied, ranging from a small orchard in the northwest corner to good bluegrass in the central portion. The kinds of cover on the various parts of the watershed are shown in figure 4.

Watershed CS-III, Colorado Springs, is a pasture area of 35.4 acres, roughly rectangular in shape, with gentle land slopes averaging 6 percent (fig. 3, p. 5). The watershed contains only one well-defined waterway, centrally located and extending about two-thirds of the way up the long axis of the area. The waterway, some 8 acres in area, has no gully but is, in effect, a broad grassy swale with a dense cover of blue grama and a few scattered weeds and other grasses. The valley soil is Nunn clay loam 10 inches deep with a B horizon 24 inches thick. The soil of the slopes is Bresser clay loam, bordering on a sandy loam. Vegetative cover on the slopes consists of blue grama with some weeds and other grasses. About 1 percent of the Bresser soil has a dense stand of sand reedgrass in patches of a few feet in diameter. There is a scattering of prickly pear and soapweed over the watershed. The area is grazed only in winter and early spring. In general, the amount and quality of cover has been improving slowly since 1938, due largely to improved soil moisture and decreased grasshopper injury. At present, the cover is typical of areas in fair condition for the High Plains of Colorado.

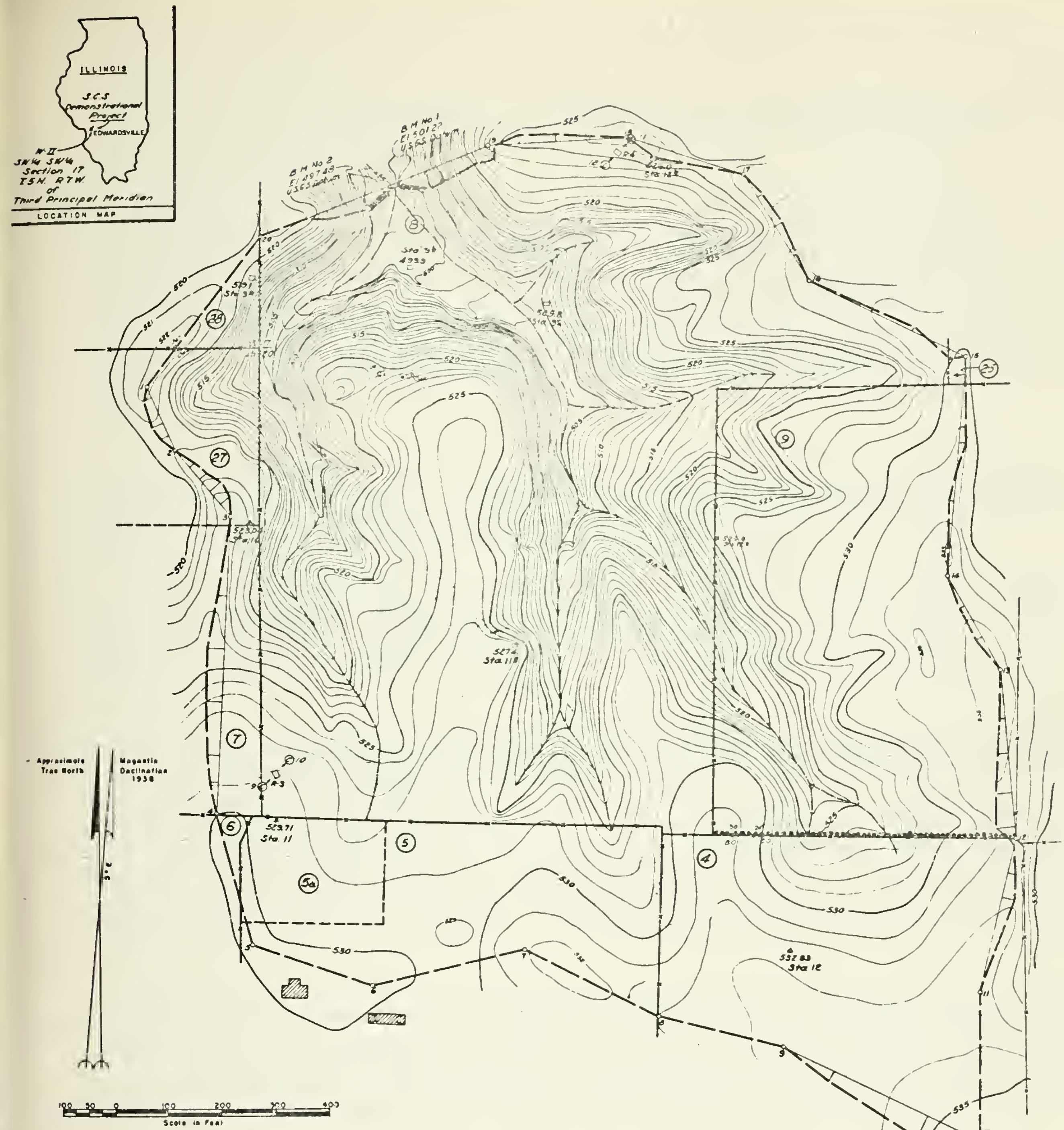
Each watershed is equipped with a broad-crested, shallow V-notch weir and a stage recorder to measure runoff. In or near each watershed are one or more recording and standard rain gages for determining rainfall. Also, in or near each watershed are thermographs, hydrographs, and maximum and minimum thermometers for obtaining and recording meteorological data. Data on soil moisture and cultural and cover conditions were also obtained for the watersheds.

Analysis of Variations in Physical Characteristics Within the Watersheds

Watershed CS-III, near Colorado Springs, was sampled with a series of 15 type F and 30 type FA infiltrometer plots in the summer and fall of 1940. The infiltrometer is described in later paragraphs under "Equipment." In order to assure a uniform but random sampling, the watershed was divided into 15 areas of nearly equal size (fig. 1, p. 3). These areas were further divided into sub-areas or sites approximately 60 feet square, which were large enough to accommodate 3 infiltration plots--one F and two FA plots. One site in each of the 15 areas on the watershed was selected by lot for infiltration studies, and the order in which the 15 sub-areas was studied was also determined by lot. In the summer and fall of 1940, initial and wet runs with infiltrometers were made on the infiltration plots in each site thus selected. The runs with one F and two FA units were made simultaneously from the same water source and in accordance with standard procedure for the use of these instruments.

A second round of single infiltrometer runs was made at prevailing soil moisture content on the same areas later in 1940. These runs showed that infiltration for all areas except the central grassy swale was essentially similar. Ten of the 15 areas were then selected by lot for installation of semi-permanent plots. These areas were equipped with tanks and stage recorders and all had rain gages for determining natural rainfall and runoff. Six of these 10 areas received no further artificial rainfall. The other 4 with tanks and the 5 without tanks received periodic applications of artificial rainfall with infiltrometers until the spring of 1942. The FA plots at the sites equipped with tanks did not have stage recorders, but the tanks measured total runoff. Runoff from natural rains was recorded for the 10 plots with tanks from the spring of 1941 through the spring of 1943. From the fall of 1940 through May 1942, random sites consisting of one F and two FA plots each, located by lot in the watershed sub-divisions, were studied.

A rainstorm on June 21, 1941, which varied from 1.56 inches at the upper end of the watershed to 1.12 inches in the northeast corner, when only four recording rain gages were in operation, indicated a need for additional recording rain gages. The four gages in operation were supplemented



CROPPING PLAN

CROP YEAR	FIELD Nº 4 6.81 Acres	FIELD Nº 5 3.95 Acres	FIELD Nº 5A 1.24 Acres	FIELD Nº 6 0.07 Acres	FIELD Nº 7 1.19 Acres	FIELD Nº 8 25.72 Acres	FIELD Nº 9 9.35 Acres	FIELD Nº 25 0.04 Acres	FIELD Nº 27 1.18 Acres	FIELD Nº 28 0.40 Acres
1937	PERMANENT PASTURE	CORN	GARDEN LOT	CORN	WHEAT	PERMANENT PASTURE	WHEAT TIMOTHY	PERMANENT PASTURE	ORCHARD TIMOTHY COVER	PERMANENT PASTURE
1938	•	WHEAT	•	WHEAT	SWEET CLOVER	•	PASTURE	•	•	TIMOTHY [illegible] CLOVER
1939	•	PASTURE SWEET CLOVER	•	PASTURE SWEET CLOVER	CORN	•	•	•	•	
1940	•	CORN	•	CORN	WHEAT (SWEET CLOVER)	•	•	•	•	-
1941	•	WHEAT	•	WHEAT	(SWEET CLOVER) PASTURE	•	•	•	•	-
1942	•	CORN 2/3 WHEAT 1/3	•	WHEAT	CORN	•	•	•	•	•
1943										
1944										
1945										
1946										
1947										
1948										
1949										
1950										
1951										
1952										
1953										

TILLAGE AND COVER MAP
WATERSHED E-II LOVE FARM
S.C.S. PROJECT ILL., 2 EDWARDSVILLE, ILL.

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H. H. BENNETT, Chief

SCALE 1 Inch = 100 Feet	Survey by R.P. Weber — Date Feb. 1937
Contour Interval 1 Foot	Plotted by R.P. Weber — Date Dec. 1938
Field Book No. 1, 2, 3, 4 and 7	Traced by M. Azinger - R.A. Peterson — Date 5-1939
	Checked by N.E. Minshall — Date 6-1939
Drawing Number 5-S-5069-C	Approved by [illegible] — Date [illegible]

FIGURE 4.--Map of Watershed E-II cover.

by 10 additional recording gages, one at each plot. These gages were in operation before the storm of July 12, 1941.

In summary, there was available for comparison records from natural and artificial rains through 1941 and the spring of 1942 on plots, and of natural rains on plots and the watershed from 1941 through the spring of 1943.

Although the soils and cover conditions within the Edwardsville watersheds varied, it was found that each watershed could be divided tentatively into smaller areas approximately homogeneous as to significant physical characteristics. Each of these areas was repeatedly sampled at random over a 2-year period for infiltration, soil moisture, soil depth, temperature, and cover. Infiltration was determined by infiltrometer (8) at about 5-week intervals from May 1940 to May 1941. The infiltrometer used was a type F infiltrometer with plots 6 feet in width and 12 feet in length. Cover conditions for each area were determined by a density count. Soil moisture determinations were made prior to each infiltrometer run. Volume weights of soil were determined from samples of the two upper soil horizons. The slopes of the plots and the temperatures during runs were recorded.

A multiple regression analysis of the results of these investigations revealed significant relations between infiltration and such factors as topsoil depth, cover density, and soil moisture. On the basis of this information, areas of similar infiltration (isopotal areas) were delineated (fig. 5, p. 9). There were 4 infiltration classes in E-I and 5 in E-II.

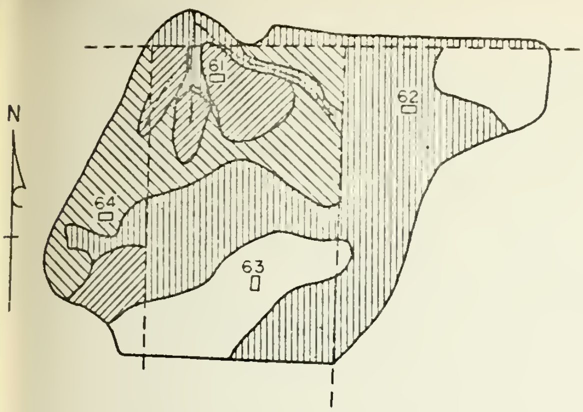
One semipermanent plot of the same dimensions as the infiltrometer plots was installed in each isopotal area. These plots were equipped with tanks, stage recorders, and recording rain gages to measure natural rainfall and runoff for comparison with the watershed data. They were operated from July 1941 through June 1943 on E-I, and from September 1941 through June 1943 on E-II.

The semipermanent plots were equipped with tanks and stage recorders specially modified to permit precise measurement of small amounts of runoff. The stage recorders were equipped with special pulleys by means of which a single traverse of the pen across the chart was made for each 0.5 foot of change in depth of water in the tanks. Special drive gears in the clocks permitted the drum to make one revolution each 6 hours. This combination resulted in 1 inch of chart equaling 25 minutes of time and 0.1 foot of head in the tank. The charts were ruled 10 to the inch for head and 25 to the inch on the time scale. This made it possible to easily read time to the half minute, and head to approximately 0.005 foot. One foot of head in the tanks was equivalent to approximately 0.8 inch of runoff from the plots. Thus, 0.005 foot of head as read on the chart was equal to 0.004 inch of runoff from the plots.

These large-scale charts and relatively small diameter tanks made possible rather precise measurements of volume of runoff from the plots, and permitted conversion of measured volumes into rates of flow with a high degree of accuracy. Any errors in the measured values are believed to be primarily those introduced by differences in temperature and quantities of sediment contained in the runoff water. Since these errors were small, no corrections were made for them. Runoff from grass and alfalfa plots contained so little soil that the water appeared clear.

Results from type F infiltrometer runs were analyzed in accordance with the methods developed by Sharp and Holtan (9). Natural hydrographs from plots and watersheds were also analyzed by this method and by techniques developed later by the same authors (10) and by Kidder and Holtan (6).

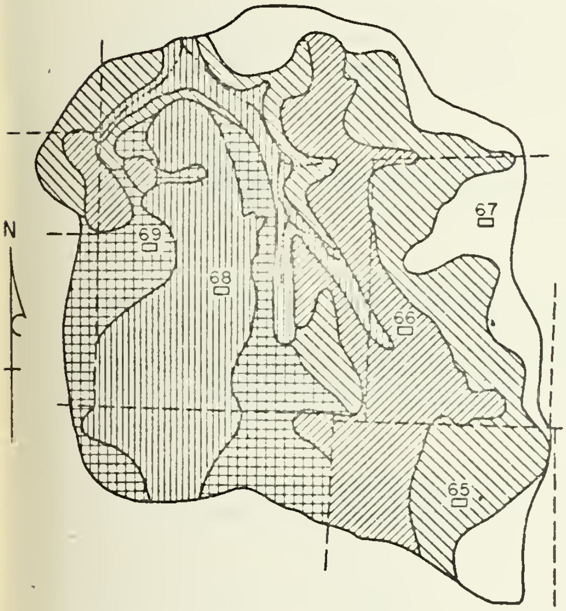
Weirs for the measurement of natural runoff from the watershed were installed in the main channel of each watershed in accordance with the method described by Harrold and Krimgold (2).



WATERSHED E-I

AREA SYMBOL	PERCENT OF WATERSHED AREA	F AT 3 HOURS (INCHES)
	12.06	0-1.6
	20.99	1.6-2.0
	19.63	2.0-2.5
	47.32	OVER 2.5

▭ RUNOFF PLOTS



WATERSHED E-II

AREA SYMBOL	PERCENT OF WATERSHED AREA	F AT 3 HOURS (INCHES)
	19.83	0-1.5
	25.68	1.5-2.0
	13.28	2.0-2.7
	24.32	OVER 2.7
	16.89 SAME AS AREA ▭ BUT DIFFERENT SLOPE AND COVER.	

▭ RUNOFF PLOTS

FIGURE 5.--Maps of Watersheds E-I and E-2, Edwardsville, showing isopotal areas.

SOIL CONSERVATION SERVICE, WASHINGTON, D.C, 1949

Results

The results of infiltrometer studies on 54 plots having different cover densities, topsoil depths, soil temperatures, slopes, and soil moisture contents at start of test showed that under Edwardsville conditions only 3 of these characteristics were significantly related to infiltration. These were cover density, soil depth, and soil moisture content (table 1, p. 11).

The content of moisture in the soil ordinarily has a pronounced effect upon both the rate and amount of infiltration. The infiltrometer measurements on the claypan soil at Edwardsville indicated that the time required for this soil to reach the point where it took up water at a constant rate was closely associated with the moisture content of the soil prior to the time water was applied (fig. 6, p. 12). If the soil moisture content was high, low rates of infiltration were soon obtained. If soil moisture content was low, infiltration rates were relatively high during the earlier parts of runs, decreased slowly and then became more or less constant at low rates. The graph (fig. 6) shows for this particular soil the rate of reduction that occurs in the amount of infiltration with increasing quantities of soil moisture.

Infiltration data for numerous plots, when sorted by seasons, showed that infiltration was closely related to season of year. The average infiltration values throughout the spring, summer, and fall months, based on studies from May 1940 to July 1941, are given graphically in figure 7, page 13. These show that infiltration usually rises to a peak in midsummer.

The differences in infiltration due to soil moisture content are accentuated by differences in cover densities. This is well illustrated by the greater infiltration on good bluegrass pasture as compared with that on poor pasture at 3 different levels of soil moisture content (fig. 8, p. 14).

Infiltrometer data indicate that under Edwardsville conditions, infiltration depends mainly upon plant cover and antecedent soil moisture. With fairly accurate information on these factors, the amount of infiltration can be determined with a degree of accuracy sufficient for practical purposes. Composite data on infiltration capacity for different conditions of vegetal cover, topsoil depth, and soil moisture are given in table 2, page 15, and graphically in figures 9 and 10, pages 16 and 17. The infiltration values shown in the graphs were obtained by infiltrometer.

The results of infiltrometer studies made on a group of plots in watershed E-I in June 1941 may be compared with infiltration on the entire watershed resulting from a natural storm which occurred in this area on July 10, 1941 (fig. 11, p. 18). In this area, as previously pointed out, antecedent soil moisture was found to have a marked effect on infiltration. Hence, it was important that the soil moisture contents be about the same for both types of measurements in order to make valid comparisons.

Since the storm of July 10 followed a storm the previous day by 24 hours, it was comparable to a wet run of the infiltrometer. Soil moisture in the upper soil horizons was probably high from the preceding rain, since an average of 1 inch of water was infiltrated during that storm. This had the effect of raising the soil moisture content to nearly 5 inches of water in the upper 21 inches of soil. The mass curve of infiltration from this storm and composite curves of mass infiltration for soil water content of 4.59 and 5.11 inches are shown in figure 11. Infiltration from the storm, with estimated soil water at 5 inches, was found to be intermediate between that from artificial rains with soil water contents of 4.59 and 5.11 inches. This indicates close agreement between the results obtained by use of data for natural and artificial storms.

On July 31, 1943, a rainstorm occurred some 3 hours following an infiltrometer run on plot 65, watershed E-II. Mass rainfall, runoff, and infiltration during this storm are illustrated in figures 12 and 13, pages 19 and 20. It would seem logical that the infiltration curve of this storm should bear a similar relation to the infiltrometer curve made 3 hours previously, as a wet run curve should bear to an initial run curve, cognizance being taken of the longer, 24-hour, recovery period of the wet run. The mass curves of infiltration from infiltrometer runs of July 31, 3 hours before the natural rain, and from runs of August 3 and 4, are included in figure 13 for comparison. It will be noted that the mass infiltration resulting from the natural rain agrees closely with

TABLE 1.--*Plot characteristics and mass infiltration (F) at 180 minutes from start of initial run (infiltrometer data) Edwardsville, Ill.*

Plot No.	Date	% Cover density X_1	Topsoil inches X_2	Antecedent moisture of soil % dry wt. 0"-7" X_3	7"-14" X_4	14"-21" X_5	Soil temp. deg. Fah. at 2" X_6	Slope % X_7	F at 180 min. Y
1	8-30-40	20	4	13.4	11.0	12.0	69	11.72	.90
2	10-16-40	15	7	20.4	14.8	13.2	56	9.62	1.47
3	8-26-40	60	14	10.7	12.7	16.0	78	.83	2.38
4	10-21-40	80	14	17.0	15.0	19.8	58	1.30	3.62
5	10-29-40	30	15	16.5	15.4	20.0	63	1.22	2.24
6	9-13-40	30	14	13.5	15.6	21.0	65	1.00	2.04
7	9-18-40	75	18	10.2	13.8	18.8	72	1.36	2.04
8	11-7-40	75	17	8.5	9.5	19.4	48	1.30	1.85
9	9-23-40	95	12	6.8	13.1	20.1	71	8.27	2.78
10	11-29-40	100	8	27.4	22.5	22.7	44	8.30	1.84
11	9-30-40	95	16	7.6	12.6	16.5	61	1.25	4.30
12	11-20-40	95	20	17.8	15.0	18.7	49	1.67	3.35
13	10-7-40	70	10	24.3	21.8	21.6	60	15.25	2.63
14	12-9-40	75	8	21.3	22.2	20.4	51	16.83	1.70
15	12-20-40	5	2	24.7	26.0	24.8	41	12.11	.42
16	10-11-40	5	3	19.2	21.6	16.5	63	11.11	.69
17	10-18-40	20	15	11.5	7.8	14.9	55	1.20	1.29
18	9-16-40	60	14	6.7	8.6	17.1	68	.58	2.80
19	10-25-40	60	12	13.0	11.3	14.9	66	.47	4.43
20	9-12-40	25	7	7.4	8.4	12.9	61	7.60	1.38
21	10-23-40	50	6	15.0	14.5	17.4	63	2.70	2.74
22	8-28-40	90	15	18.8	12.4	14.6	76	.83	2.00
23	11-22-40	100	11	19.5	12.8	16.5	53	4.60	2.57
24	9-20-40	20	8	5.0	12.6	11.6	74	2.70	1.55
25	11-18-40	50	14	9.9	8.7	14.1	47	.25	2.23
26	9-27-40	5	3	9.4	15.4	15.5	64	8.40	.99
27	10-2-40	100	14	6.4	7.2	10.4	64	2.70	4.46
28	12-6-40	60	7	21.9	22.0	18.2	48	12.00	2.54
29	10-9-40	5	0	17.5	12.4	12.0	60	5.50	.80
30	12-12-40	85	7	22.9	18.6	13.9	40	8.70	1.25
31	12-23-40	5	3	25.2	25.4	27.4	40	12.40	.83
32	10-14-40	40	2	18.0	20.2	16.6	66	7.80	1.50
33	11-4-40	40	13	9.7	10.8	15.7	57	0	3.32
34	3-25-41	80	9	28.8	26.6	27.0	42	12.20	2.38
35	5-27-41	25	6	13.4	19.9	19.1	72	2.90	1.60
36	5-28-41	35	14	12.0	13.9	22.6	75	1.30	3.21
37	6-17-41	10	14	18.0	18.1	23.4	67	1.00	2.21
38	6-16-41	15	10	19.0	18.1	22.5	67	1.90	2.94
39	6-9-41	5	7	6.3	8.5	16.1	73	.80	2.54
40	6-6-41	15	11	14.0	20.0	20.7	69	5.20	1.85
41	5-29-41	25	16	8.0	14.3	24.6	70	.20	3.26
42	5-5-41	100	9	27.8	26.4	27.9	65	1.05	1.33
43	5-24-41	40	14	9.8	12.2	20.6	61	.20	4.09
44	5-8-41	95	11	25.3	24.5	21.0	60	.50	2.37
45	5-22-41	60	7	12.8	21.0	20.4	75	18.20	1.69
46	5-13-41	100	6	24.8	28.5	26.0	64	10.70	1.60
47	5-14-41	60	7	22.0	23.4	25.7	63	3.70	2.07
48	5-12-41	75	11	23.1	23.1	26.2	61	.75	1.61
49	5-15-41	85	13	20.7	21.9	26.1	71	.80	1.98
50	5-9-41	50	11	24.8	23.7	22.9	62	.95	1.42
51	5-16-41	65	9	19.3	21.4	24.5	70	2.70	1.75
52	5-21-41	95	9	20.2	24.4	26.9	74	3.00	3.04
53	5-20-41	90	10	22.3	21.5	25.5	68	1.60	1.96
31A	1-14-41	5	3	26.1	27.7	27.5	39	10.40	1.37

$n = 54$

X_1 – Cover density basal area of plants in % of plot area.

X_2 – Topsoil in inches depth

X_3 – Antecedent soil moisture in % of soil dry wt. 0" – 7"

X_4 – Antecedent soil moisture in % of soil dry wt. 7" – 14"

X_5 – Antecedent soil moisture in % of soil dry wt. 14" – 21"

X_6 – Temperature of topsoil in deg. fah.

X_7 – Slope of plot surface in %

Y – Mass infiltration at 180 minutes from start of run.

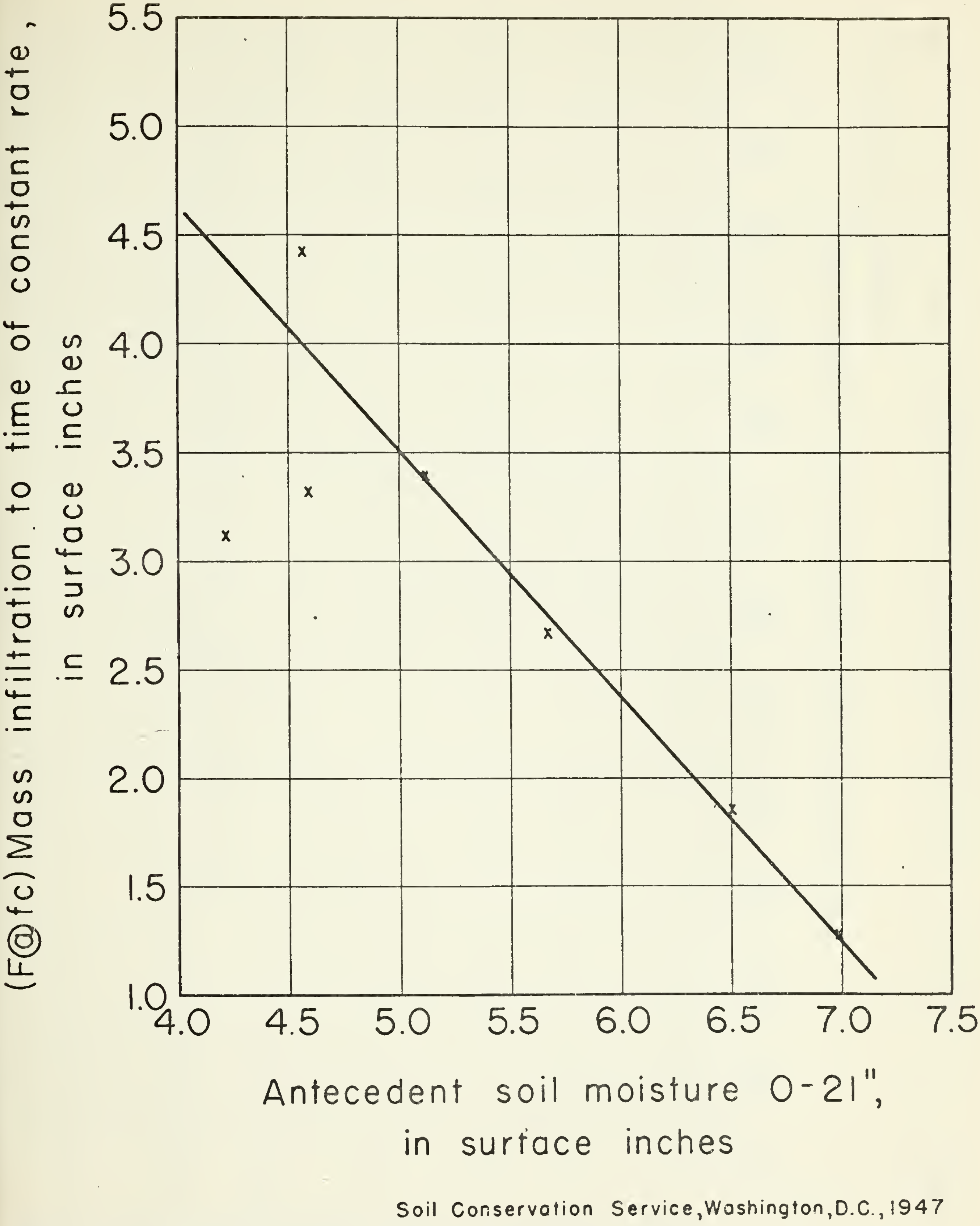


FIGURE 6.--Relationship of water in upper 21 inches of soil at start of run to the mass infiltration before the rate of infiltration becomes constant, Edwardsville.

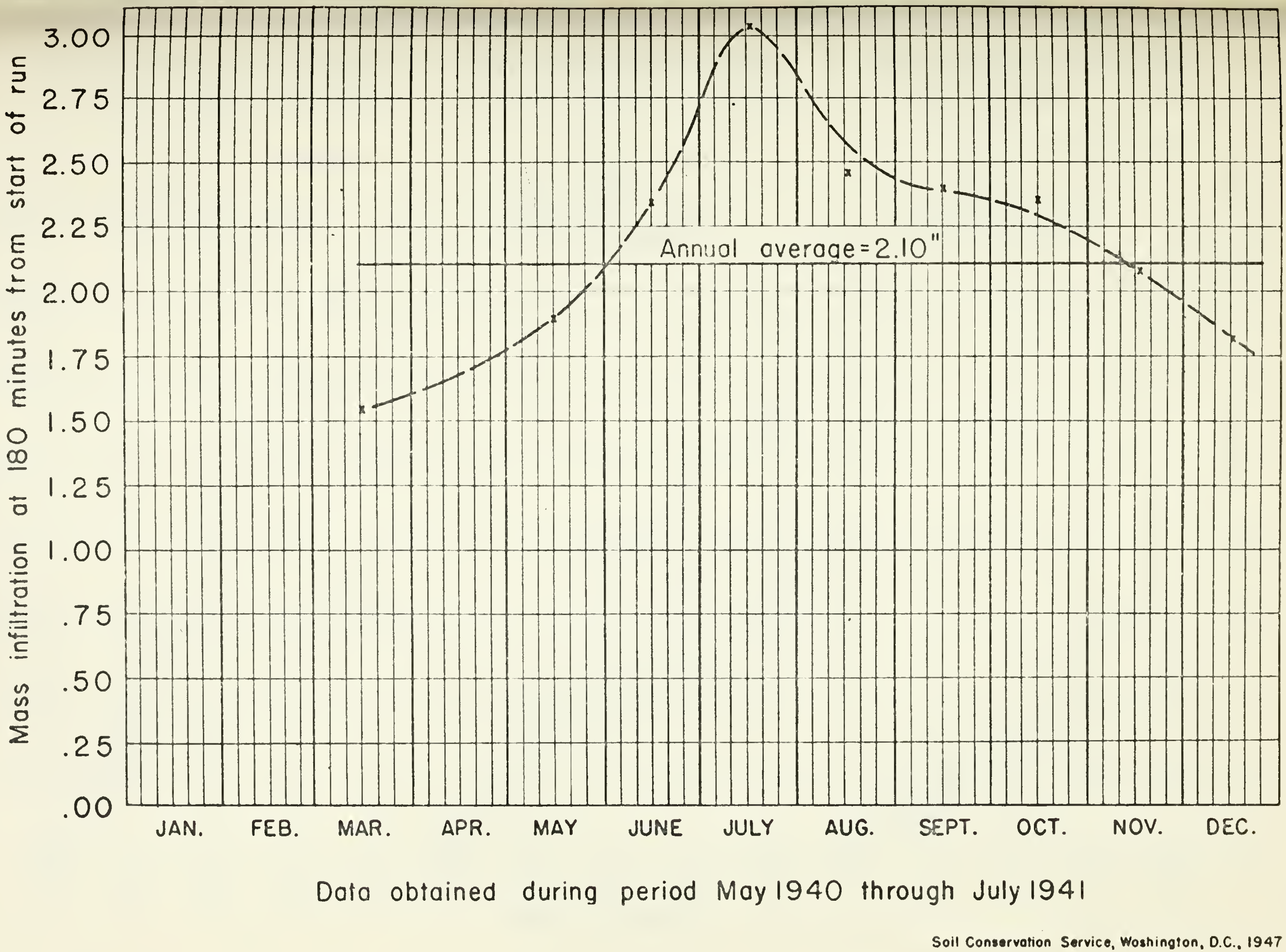


FIGURE 7.--Deviation of mass infiltration monthly means from the annual average as indicated by "F" unit infiltrometer data. Edwardsville.

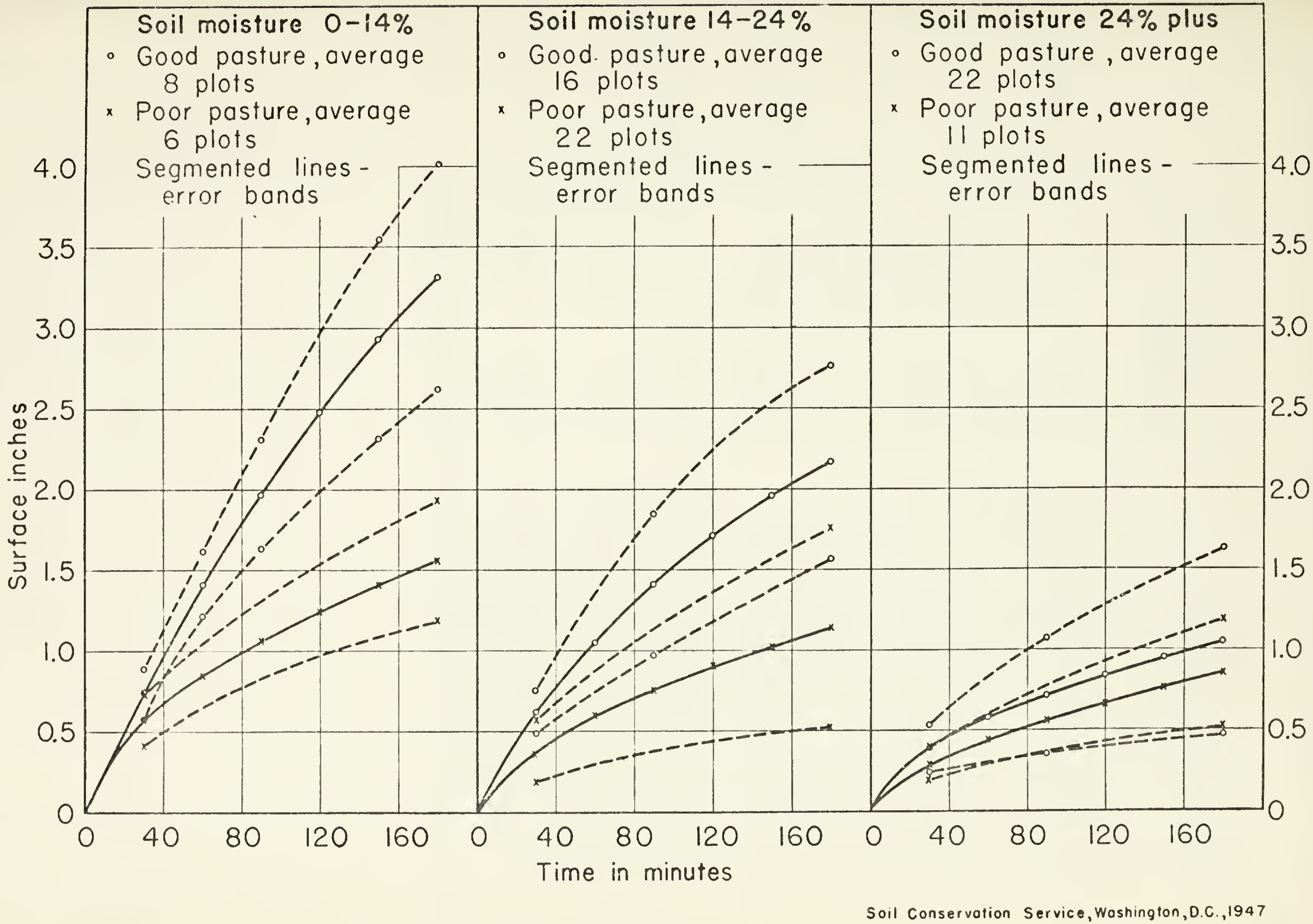


FIGURE 8.--Mass infiltration on soils of less than 13 inches topsoil as affected by vegetative cover and by soil moisture, Edwardsville.

TABLE 2.--*Average cumulative amounts of infiltration for different conditions of vegetal cover and soil moisture data from infiltrometer tests at Edwardsville*

Cover	Topsoil depth	Soil moisture	No. of runs	Minutes from time of start					
				30	60	90	120	150	180
	Inches	*Percent*			*Surface Inches*				
Good pasture	13+	0.14	15	0.76	1.39	1.93	2.40	2.82	3.17
Good pasture	13+	14-24	16	.57	.98	1.33	1.58	1.77	1.92
Good pasture	13+	24+	20	.40	.56	.68	.78	.86	.94
Good pasture	0-13	0-14	8	.75	1.42	1.97	2.48	2.93	3.32
Good pasture	0-13	14-24	16	.62	1.05	1.41	1.71	1.96	2.17
Good pasture	0-13	24+	22	.39	.57	.71	.84	.95	1.05
Poor pasture	0-13	0-14	6	.57	.85	1.06	1.24	1.41	1.56
Poor pasture	0-13	14-24	22	.37	.60	.75	.90	1.03	1.14
Poor pasture	0-13	24+	11	.29	.43	.55	.66	.76	.85
Rank alfalfa	0-17	0-14	10	.79	1.36	1.79	2.14	2.43	2.69
Rank alfalfa	0-17	14-24	18	.56	.90	1.14	1.34	1.50	1.63
Rank alfalfa	0-17	24+	10	.40	.62	.79	.94	1.08	1.22
Cut alfalfa	0-17	0-14	9	.71	1.20	1.55	1.82	2.03	2.19
Cut alfalfa	0-17	14-24	14	.56	.92	1.19	1.40	1.58	1.73
Cut alfalfa	0-17	24+	12	.40	.62	.78	.94	1.07	1.20

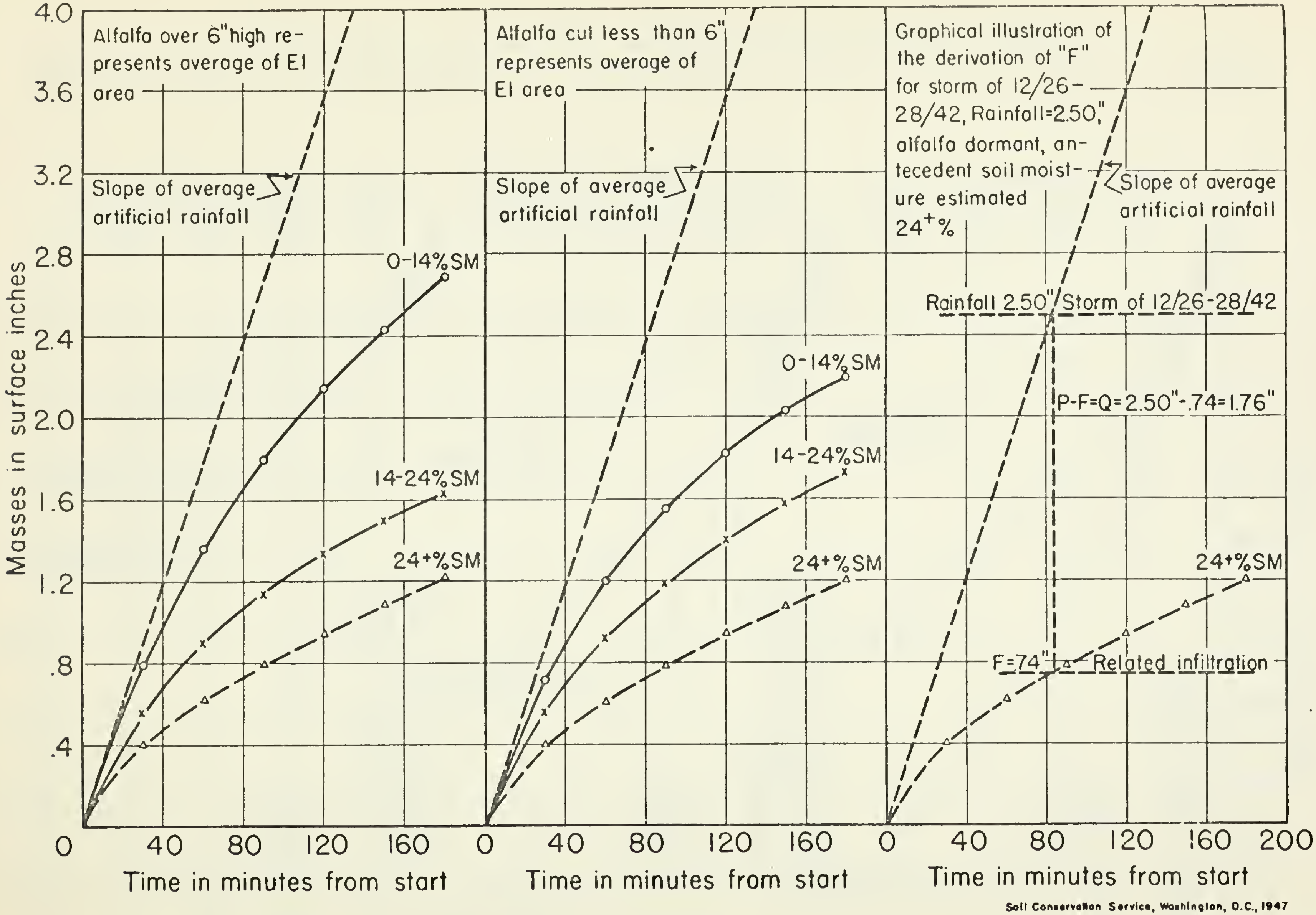


FIGURE 9.--Composite infiltration curves as determined by the infiltrometer for various conditions of alfalfa cover and of antecedent soil moisture, together with a graphical illustration of the derivation of F for the natural storm of December 26-28, 1942, Watershed E-I, Edwardsville.

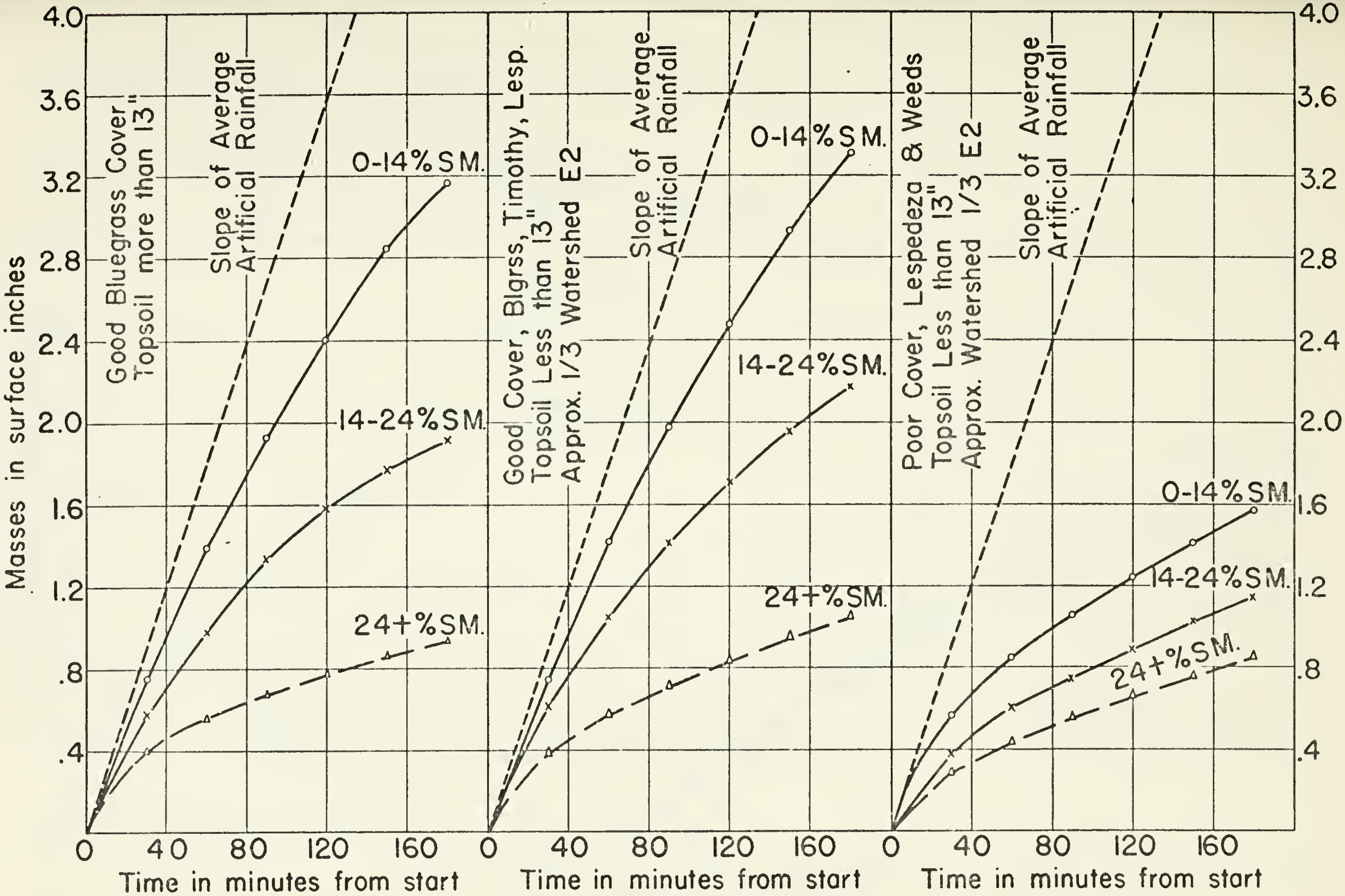


FIGURE 10.--Composite infiltration curves as determined by the infiltrometer for various conditions of cover and antecedent soil moisture, Watershed E-II, Edwardsville.

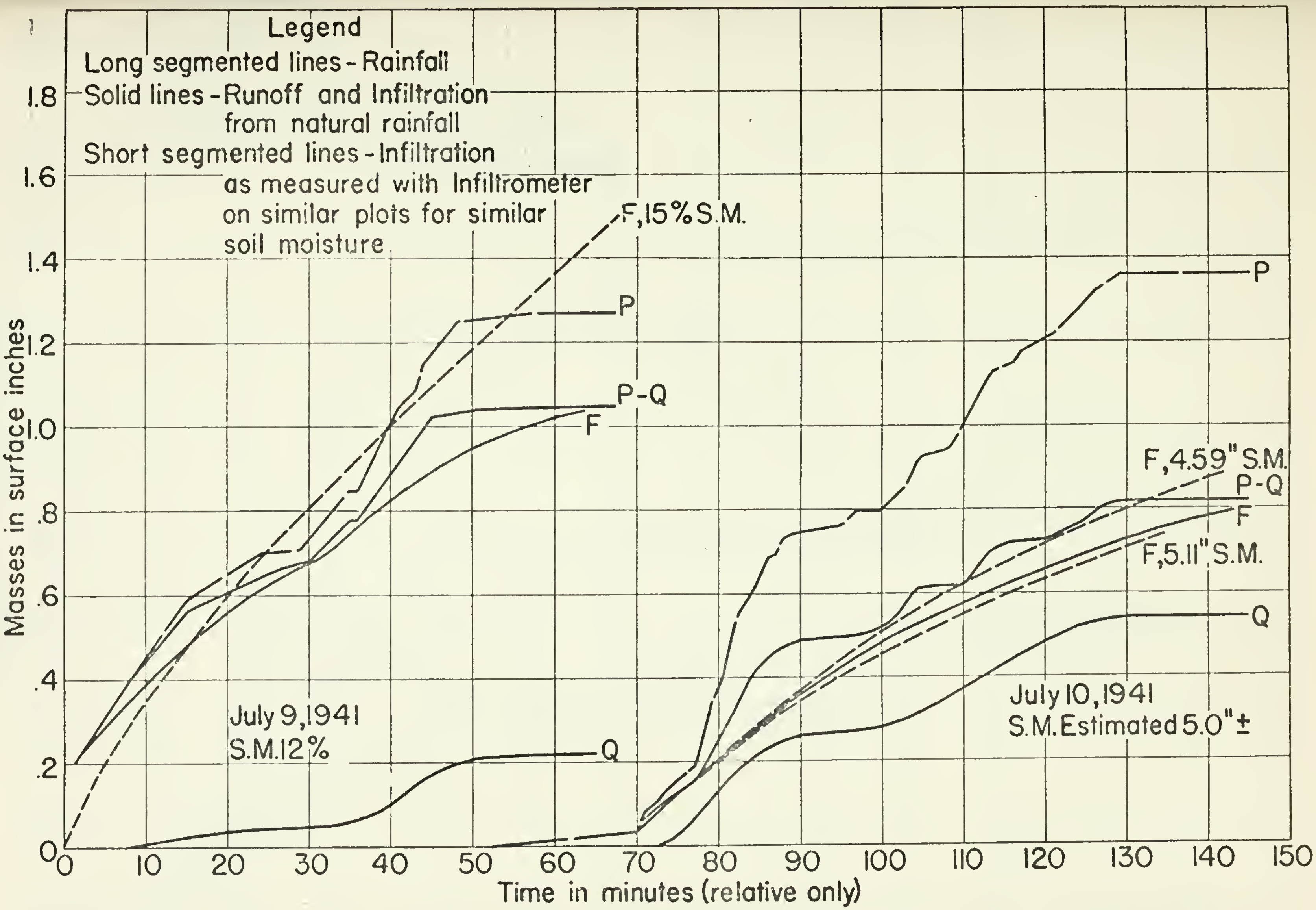


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FIGURE 11.--Comparative results, storms of July 9 and 10, 1941, with infiltrometer results of June 1941 on Watershed E-I, Edwardsville.

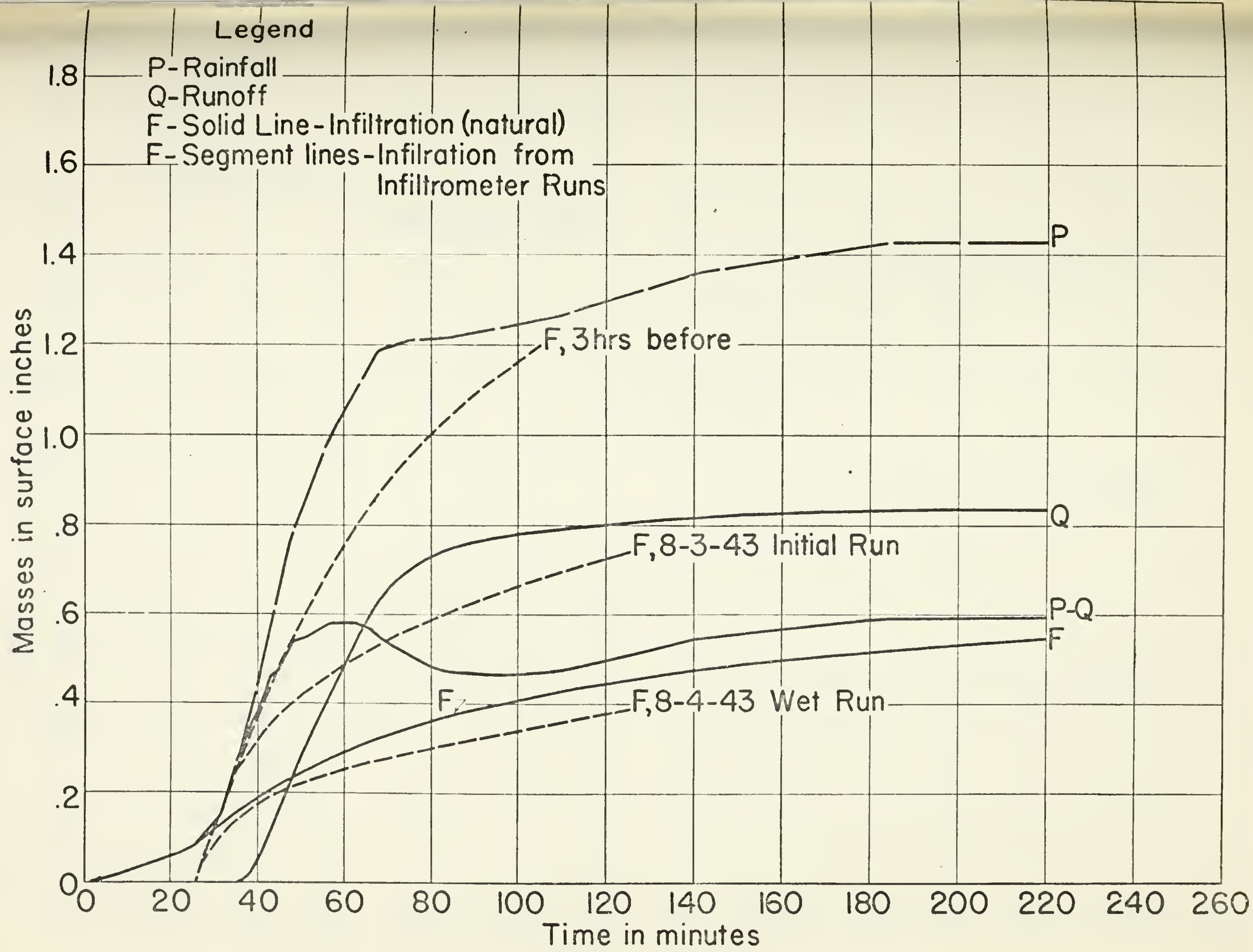

FIGURE 12.--Comparison of infiltration from the storm of July 31, 1943, with infiltration as determined by the infiltrometer before and after the storm, Plot 65, Edwardsville.

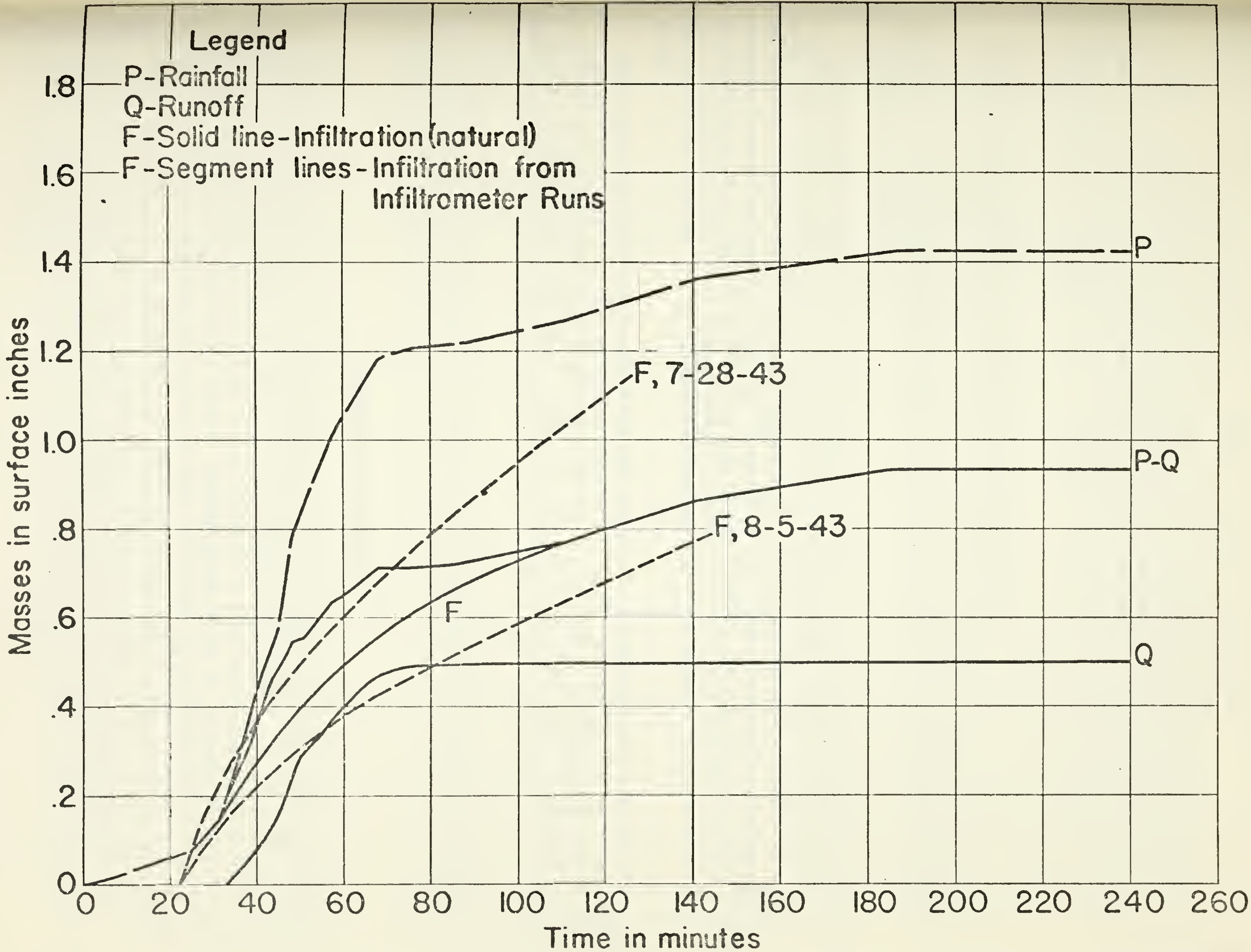

FIGURE 13.--Comparison of infiltration from the storm of July 31, 1943, with infiltration as determined by the infiltrometer before and after the storm, Plot 66, Edwardsville.

the mass infiltration as determined from the infiltrometer wet run on August 4, during the period from the time the supply (rainfall) was adequate to the end of the wet run.

On plot 66, infiltrometer runs were made on July 28, 3 days before the storm of July 31, 1943, and again on August 5, 5 days after the storm. Soil moisture contents at the beginning of this storm were probably intermediate between those at the beginning of the infiltrometer runs. Mass infiltration for the natural storm was also intermediate between the infiltrations obtained by the infiltrometer before and after the storm (fig. 13, p. 20). The effect of antecedent soil moisture on infiltration was apparently the same regardless of whether the water was naturally or artificially supplied.

On plot 67, infiltrometer runs made prior to this same storm on July 27, and again on August 6, indicated that much the same relations existed as for plot 66.

These few examples indicate that for the soil and other conditions existing at Edwardsville the infiltration rate as determined by infiltrometer is essentially the same as for natural rainfall, provided soil moisture content is comparable and natural rainfall rates are adequate to supply water for capacity infiltration.

Characteristics of rainfall, and the response of different soils and cover densities to rainfall, are so varied that no uniform relationship may be expected between amounts of rainfall and amounts of runoff. A rainstorm of 3 inches falling in 12 hours, for instance, might cause no runoff, whereas 3 inches falling in 2 hours would probably cause high amounts of runoff. The wide variation in runoff that actually occurred on watershed E-I is well illustrated by plotting rainfall and runoff on a chart (fig. 14, p. 22). The wide scatter of points shown in this chart indicates the lack of consistency that exists between the total rainfall on a watershed from different storms and the amount that runs off, and the fallacy of attempting to predict runoff on the basis of rainfall alone.

Mass watershed runoff determined from unit storm data agrees fairly well with that obtained by weighting plot runoffs on isopotal areas (figs. 15 and 16, pp. 23 and 24). The watershed runoff computed by averaging plot runoffs, for most storms in watershed E-I, was greater than the actual measured runoff, although the difference was small. On watershed E-II, runoff from the watershed, computed by this method, was generally higher than that shown by the plots in the watershed.

Since it has been shown that artificial rain will yield as reliable information on infiltration as natural storms, the infiltration from any storm for which the rainfall is known may, under the limitations noted for this area, be determined by comparison with the measured infiltration obtained by the infiltrometer.

ESTIMATING THE RUNOFF

Figure 9 (right), page 16, is a graphical illustration of a method for deriving the amount of infiltration for a given amount of rainfall, using the storm of December 26-28, 1942, as an example. In this storm, rainfall equaled 2.50 inches (table 3, page 25). Antecedent soil moisture at this time was very high due to frequent previous rain and snow. The alfalfa on the watershed was dormant and beaten down. Infiltration under these conditions is most nearly expressed by the lower curve designated "alfalfa less than 6 inches" (middle graph of fig. 9). In order to illustrate how this curve is used to determine the amount of water infiltrated, the pertinent parts of the middle graph are duplicated in figure 9 (right). Using this graph, the rainfall (2.50 inches) is located on the artificial-rainfall curve from the scale at the left. The related infiltration is found by dropping vertically to the infiltration curve for high soil moisture (24 percent) and projecting the point of intersection horizontally to the scale at the left. In this illustration, related infiltration is found to be 0.74 inch. Consequently, runoff equals 2.50 inches minus 0.74 inch or 1.76 inches. This figure--1.76 inches--compares favorably with 1.84 inches, the measured runoff from the watershed (table 4, p. 27).

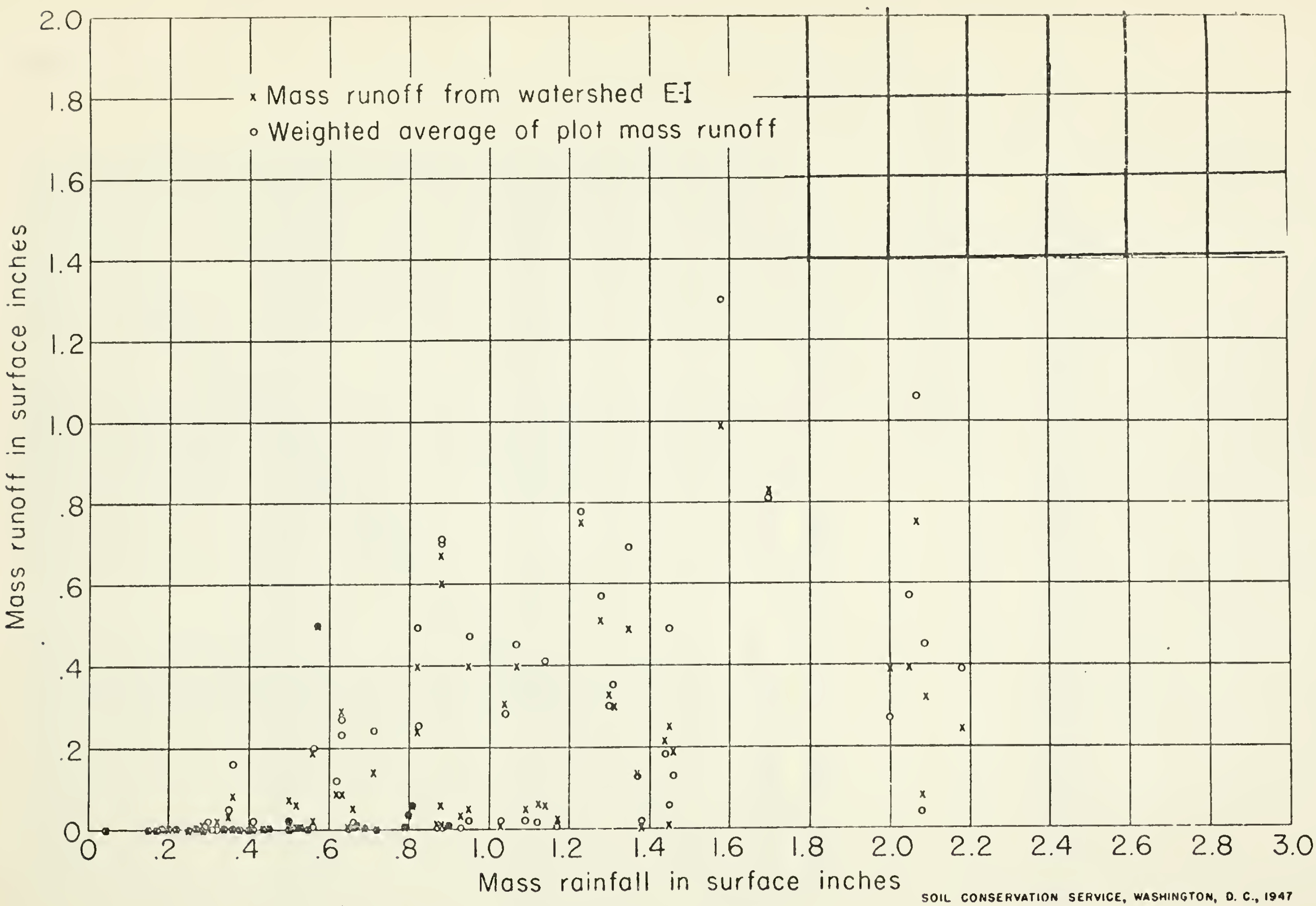

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FIGURE 14.--Plot and watershed runoff versus rainfall, showing wide scatter of points and lack of relationship pattern, Watershed E-J, Edwardsville.

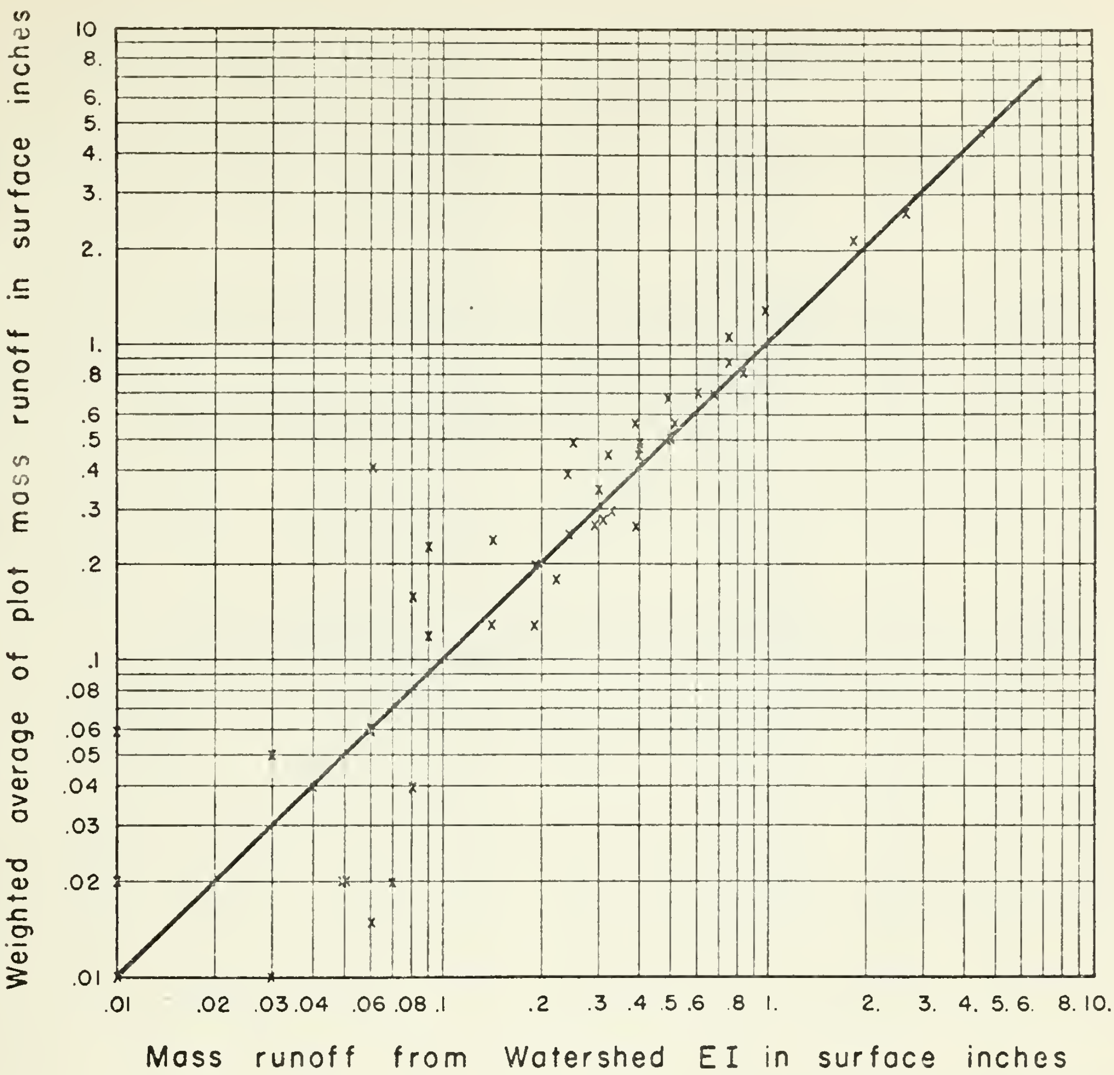

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FIGURE 15.--Relationship between weighted average of plot runoff and measured runoff from Watershed E-I, Edwardsville.

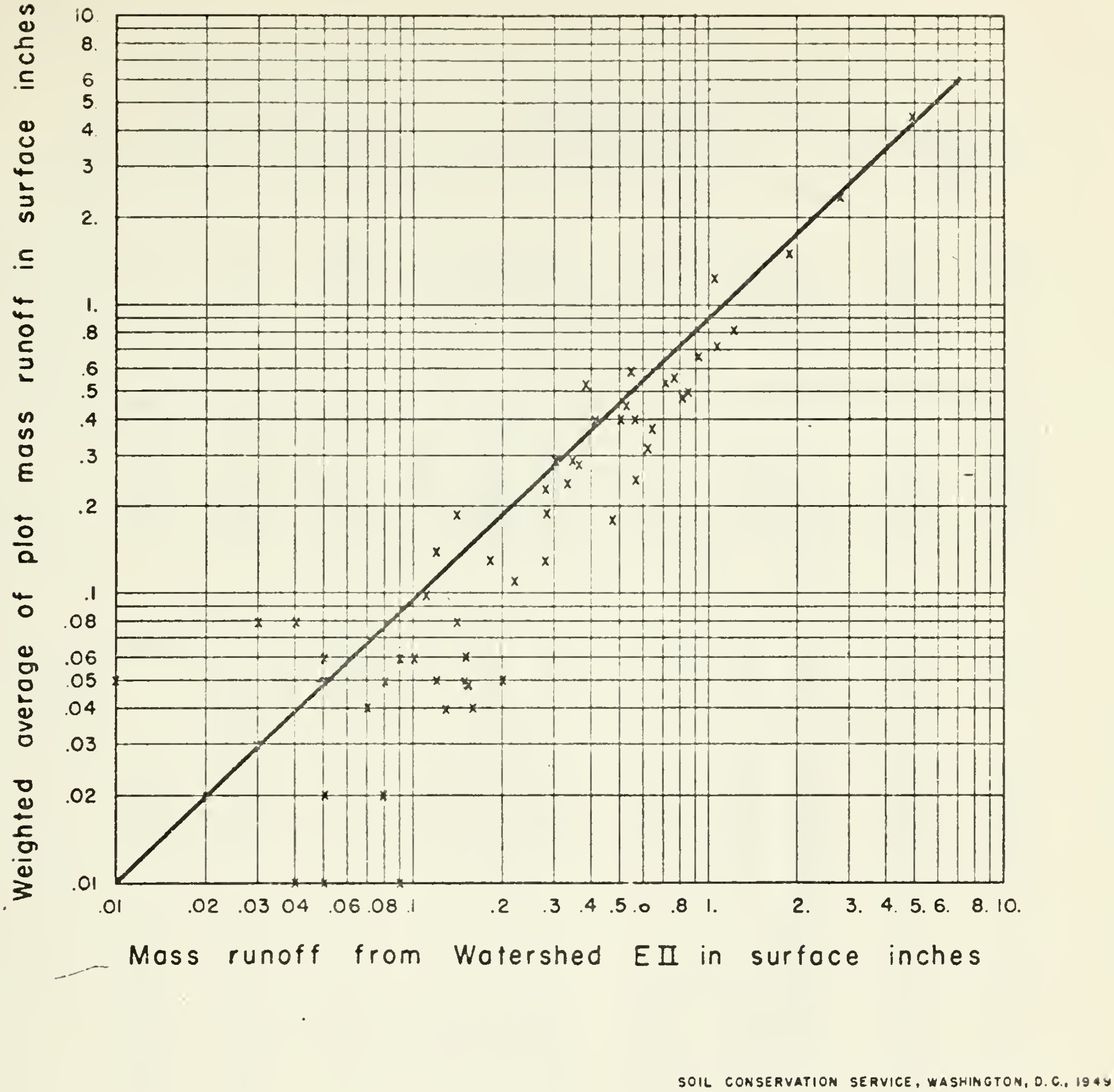


FIGURE 16.--Relationship between weighted average of plot runoff and measured runoff from Watershed E-II, Edwardsville.

TABLE 3.--*Rainfall and runoff from plots and watershed E-I, Edwardsville, Ill.*

Date	Amount of total runoff							Watershed runoff	Rainfall	E-I maximum rate	Average of plots maximum rate
	Plot 61	Plot 62	Plot 63	Plot 64	Total	Averages: Arithmetic	Averages: Weighted by percent area[1]				
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1941											
July 9	0.46	0.59	0.11	0.25	1.41	0.35	0.41	0.06	1.14	0.13	0.95
July 10	.80	.42	.33	.62	2.17	.54	.49	.25	1.45	.26	1.72
Aug. 24	.09		.05	.20	.34	.08	.06	.01	1.45	.17	.27
Aug. 25									.40		
Sept. 1									.25		
Sept. 2	1.20	.29	.45	.93	2.87	.72	.57	.39	2.05	.46	1.85
Sept. 4-5									.38		
Sept. 9									.41		
Sept. 24-25	.13			.02	.15	.04	.02		1.38		.06
Sept. 29-30									.72		
Oct. 5	.10		[2]T	.01	.115	.03	.02		.30		.39
Oct. 7	.01		[2]T	[2]T	.015	[2]T	[2]T		.29		
Oct. 9	.30	.01	.02	.10	.43	.11	.06	.06	.81	.12	.63
Oct. 14	.11		.01	.03	.15	.04	.02	.01	.41	.02	.40
Oct. 17-18	.60	.04	.10	.12	.86	.225	.13	.19	1.46	.13	.93
Oct. 21	.09		[2]T	.01	.10	.025	[2]T	.02	.50	.01	.06
Oct. 22-23	.96	.12	.35	.26	1.69	.42	.30	.33	1.30	.19	1.02
Oct. 26	.02				.02	[2]T	[2]T		.36		.01
Oct. 30-31	.81	.08	.09	.55	1.53	.38	.27	.39	2.00	.07	.27
Nov. 5-6	.83	1.23	.78	1.11	2.95	.74	.06	.75	2.07	.10	.18
Nov. 22-26	.03				.03	[2]T	[2]T		.88	Rain and Snow	
Dec. 22-23								[2]T	.44		
Dec. 25-26								[2]T	.29		
1942											
Jan. 30-31	[2]T				[2]T	[2]T			.88		
Feb. 4-5	.03	.22	.20	.29	.74	.185	.20	.19	.56	.08	.18
Feb. 5-6-7	.10	.81	.74	.82	2.47	.62	.71	.60	.88	.06	.10
Feb. 9-12								[2]T	.20	Snow	
Feb. 16-17		.48	.01	.01	.50	.12	.23	.09	.63	.02	
Feb. 27		.02	.01	[2]T	.034	[2]T	[2]T	.02	.32	Snow	
Feb. 28-March 1		.02		.01	.02	[2]T	.01	.01	Melting Snow		
Mar. 2		.02	.01		.03	[2]T	.01	[2]T	.05	Snow	
Mar. 7-8		.50	.01	.02	.53	.13	.24	.14	.71	.05	.05
Mar. 12-13	.01	.22	.01	.06	.30	.07	.12	.09	.62	.02	.02
Apr. 7	[2]T	.01			.014	[2]T	[2]T	.02	1.17	.01	
Apr. 8-10	.01	.88	.01	.15	1.051	.26	.45	.32	2.09	.03	.03
May 3	.02	[2]T			.024	[2]T	.02	.01	1.03	.03	.05
May 5-6	.06	.02	.01	.03	.12	.03	.02	.05	1.09	.05	.20
May 13	.03	.01			.04	.01	[2]T	[2]T	.67	.02	.10
May 15	.04	[2]T		.01	.05	.01	[2]T	.03	.93	.02	.01
May 17-18	.01			[2]T	.01	[2]T	[2]T	.01	.67		.03
May 31									.36		
June 1	.01	[2]T			.014	[2]T	[2]T	[2]T	.69	.02	.02
June 9									.31		
June 13	.34	.13	.05	.08	.60	.15	.13	.14	1.37	.20	.58
June 15									.31		
June 18								[2]T	.52		
June 20-21	.52	.37		.52	1.41	.35	.35	.30	1.31	.40	1.98
June 21 (p. m.)	.05		.25		.27	.07	.05	.03	.35	.03	.23
June 25									.50		
June 26	.82	.77	.67	1.02	3.28	.82	.81	.83	1.70	.65	3.50
July 7-8	.10		.01	.03	.14	.03	.02	.05	.95	.07	.22
July 8-9	2.31	2.66	2.98	2.43	10.38	2.60	2.63	2.63	4.30	1.41	3.49
July 9-10	.58	.75	.66	.67	2.66	.67	.70	.67	.88	.60	2.21
July 12	.04	.01	.03	.03	.11	.03	.02	.07	.50	.06	.12
July 14	.02		.01	.01	.04	.01	[2]T	.06	.52	.02	.02
July 21	.03	.01			.04	.01	[2]T	.02	.56	.03	.05
July 26									.31		
Aug. 2-3									.37		
Aug. 6	.24	.13	.21	.22	.80	.20	.18	.22	1.44	.34	1.03
Aug. 7	.43	.21	.25	.22	1.11	.28	.25	.24	.82	.33	2.09
Aug. 15								[2]T	.90		
Sept. 8								[2]T	.66		
Sept. 19									.45		
Sept. 26									.15		
Oct. 5									.31		
Oct. 19									.17		
Oct. 29-30	.25	.01		.02	.28	.07	.04	.08	2.08	.04	.07
Nov. 4-5	.11		.01		.12	.03	.015	.06	1.12	.03	.02
Nov. 7									.18		
Nov. 9									.22		
Nov. 17 (a. m.)	.01				.01	[2]T	[2]T		.34		
Nov. 17-18	.52	.22	.14	.39	1.27	.32	.28	.31	1.04	.56	1.56
Nov. 21	.10	.01		.02	.13	.03	.02	.05	.66	.05	.16
Nov. 21-22-23	.54	.84	.12	.40	1.90	.475	.57	.51	1.28	.10	.24
Dec. 10			.01		.01	[2]T	[2]T	[2]T	Melting Snow		
Dec. 22-24	.02		.05		.07	.017	.01	.03	Melting Snow		
Dec. 26-28	1.18	2.31	2.38	2.12	7.99	1.99	2.15	1.84	2.50	.47	.69

[1] Percent watershed area represented by each plot is 12.06, 47.32, 19.63, and 20.99 for plots 61, 62, 63, and 64 respectively.
[2] Trace of runoff.

TABLE 3.--*Rainfall and runoff from plots and watershed E-I, Edwardsville, Ill.*--Continued

Date	Amount of runoff								Rainfall	E-I maximum rate	Average of plots maximum rate
	Plot 61	Plot 62	Plot 63	Plot 64	Total	Averages		Watershed runoff			
						Arithmetic	Weighted by percent area[1]				
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1943											
Jan. 14								[2]T		.01	Snow
Jan. 26								[2]T			Snow
Feb. 3	0.27	0.07	0.54	0.49	1.37	0.34	0.27	.29	0.63	0.13	.30
Feb. 5		.02			.02	[2]T		[2]T	.17		
Mar. 10								.01	.79		
Mar. 15-16	.10	.75	.78	.83	2.46	.64	.69	.49	1.35	.12	.31
Mar. 18-19	.19	.50	.51	.64	1.84	.46	.49	.40	.82	.15	.46
Apr. 11-12									.44		
Apr. 22-23									.65		
Apr. 25									.38		
May 7-7	.16	.64	.17	.18	1.15	.29	.39	.24	2.18	.11	.42
May 8	.01	.22	.24	.04	.51	.13	.16	.08	.36	.03	.10
May 9-10-11-12	.38	1.21	[3]1.21	1.26	5.01	1.25	1.30	.99	1.58	.22	.45
May 14-15-16	.13	.40	.77	.47	1.77	.44	.45	.40	1.07	.17	1.00
May 16-18	4.37	4.81	[3]4.81	4.67	18.66	4.66	4.72	4.49	5.23	1.19	3.28
May 19-20-21	.15	.50	[3].50	.45	1.88	.47	.50	.50	.57	.15	.90
May 24								[2]T	.32		
June 4									.55		
June 5			[2]T		[2]T	[2]T	[2]T	.01	.87	.02	
June 6-7	.58	.92	.88	.50	2.88	.72	.78	[3].75	1.23		1.76
June 10	.27	.48	.62	.41	1.78	.44	.47	.40	.95	.29	1.44
June 15-16	.03	.04	.09	.02	.18	.045	.04	.04	.80	.03	.14
June 20	[2]T				[2]T	[2]T	[2]T	[2]T	.53		
June 26								[2]T	.27		

[1]Percent watershed area represented by each plot is 12.06, 47.32, 19.63, and 20.99 for plots 61, 62, 63, and 64 respectively.

[2]Trace of runoff.

[3]Estimated.

TABLE 4.--*Rainfall, runoff, and rainfall minus related infiltration for storms producing runoff, watershed F-I, Edwardsville*

Date	Height of alfalfa	Estimated antecedent soil moisture	Runoff	Total rain-fall	Related infiltra-tion (F)	Rainfall minus related F
	Inches		*Inches*	*Inches*	*Inches*	*Inches*
1941						
July 9.......	14	low	0.06	1.14	0.95	0.19
July 10......	14	Medium	.25	1.45	.78	.67
Sept. 2......	cut	low	.39	2.05	1.31	.74
Oct. 9.......	8	medium	.06	.81	.50	.31
Oct. 17 & 18.	8	do	.19	1.46	.78	.68
Oct. 22 & 23.	8	do	.33	1.30	.73	.57
Oct. 30 & 31.	8	low	.39	2.00	1.47	.53
Nov. 5 & 6...	8	medium	.75	2.07	.99	1.08
1942						
Mar. 7 & 8...	0	high	.14	.71	.33	.38
Mar. 12 & 13.	0	do	.09	.62	.29	.33
Apr. 7.......	12	low	.02	1.17	.97	.20
Apr. 8 & 10..	12	medium	.32	1.03	.61	.42
May 5 & 6....	14	do	.05	1.09	.64	.45
June 13......	36	low	.14	1.37	1.10	.27
June 20 & 21.	36	medium	.30	1.31	.73	.58
June 26......	36	do	.83	1.70	.87	.83
July 8 & 9...	cut	do	2.63	4.30	1.54	2.76
July 9 & 10..	cut	high	.67	.88	.39	.49
Aug. 6.......	15	low	.22	1.44	1.15	.29
Aug. 7.......	15	medium	.24	.82	.50	.32
Nov. 17 & 18.	3	do	.31	1.04	.63	.41
Nov. 21 & 23.	3	do	.51	1.28	.73	.55
Dec. 26 & 28.	0	high	1.84	2.50	.74	1.76
1943						
Mar. 15 & 16.	0	medium	.49	1.35	.76	.59
Mar. 18 & 19.	0	high	.40	.82	.36	.46
May 6 & 7....	10	low	.24	2.18	1.57	.61
May 9 & 12...	10	high	.99	1.55	.56	.99
May 14 & 16..	12	do	.40	1.07	.45	.62
May 16 & 18..	14	do	4.49	5.23	1.31	3.92
May 19 & 21..	16	do	.50	.57	.29	.28
June 10......	18	do	.40	.95	.41	.54

Although the Edwardsville data show that there is reasonably good agreement between mass runoff from plots and watershed, the volume of water draining off a watershed in a storm does not cease immediately as the storm lets up, nor does it increase quickly as the rainfall increases, because some rainwater is retarded in its movement to the outlet. The runoff from small plots changes more quickly with changes in rain intensity (figs. 17 to 20, incl., pp. 29 to 32). Figures 17 and 18 are hydrographs of 2 different storms occurring on watershed E-I, while figures 19 and 20 are hydrographs of the same storm on E-II. In brief, these graphs reveal the effects of detention, retention, and infiltration on runoff at various times during a storm.

They illustrate the relationship of the hydrographs from small 6 x 12 foot rectangular plots lying within the watershed to the hydrograph of the entire watershed as a unit. As indicated earlier the small plots were of sufficient number and of proper location to provide representation of all isopotal areas within the watershed. Each small plot therefore provides a hydrograph of flow from each 6 x 12 foot area within its respective isopotal area. Due to the size of these plots, flow from them has been considered as overland flow. This, then, for a given storm may be presumed to be a measure of the quantity of water flowing off the watershed. The overland flow from isopotal areas was therefore expressed in "watershed surface inches." The proportion of the isopotal area to the watershed area is directly applied to compute this conversion. A summation (sigma) of these overland flow hydrographs from the isopotal areas in "watershed surface inches" is essentially similar to the overland flow hydrograph of the watershed (labeled sigma Q in figs. 17 to 20).

A very good check of this derived hydrograph of overland flow is provided by analysis of the observed watershed hydrograph. Using "Time Condensation" (3) in the analysis of the observed runoff hydrograph, a curve of excess rainfall (labeled sigma Q + detention in figs. 17 to 20) is obtained. This curve represents the water in excess of infiltration and other retentions which at any given time is free to, and which will eventually, run off. It differs from observed runoff at any given time by the amount of water needed to wet surfaces and provide head for flows of runoff. Since this water originates on the isopotal areas and the observed runoff is water which has traversed the watershed, it is logical that the status of overland flow water (plot runoff) should be somewhere between the excess rainfall curve (sigma Q + detention) and the observed runoff curve. Examination of figures 17 to 20 indicates the excellent conformity of the sigma Q curve to this idea. The one case (fig. 19) where the curves depart from this pattern is undoubtedly due to the known presence of return flow seepage. A very reasonable estimate of return flow seepage as indicated on the graph virtually eliminates this discrepancy. The estimate of return flow seepage can be easily checked by analysis of the watershed hydrograph.

INFORMATION ON INFILTRATION IN THE COLORADO SPRINGS WATERSHED

Similar, but much less comprehensive infiltration-runoff studies were conducted on watershed CS-III near Colorado Springs, Colo. Conditions on this area were markedly different from those prevailing on the Edwardsville, Ill., watersheds. The soils are younger and more permeable. The vegetation is a native range type consisting mainly of blue grama. The watershed has a youthful drainage pattern with no incised drainage ways, and the slopes are relatively gentle and uniform. There were only 2 dominant soil-cover complexes. The grassy swale in the lower part of the drainage area extends two-thirds of the distance up the valley and has a deep permeable soil. The major portion of the valley consisted of a uniform hillside soil of lower permeability.

Due to the lack of sufficient rain-producing storms and infrequent periods of runoff from the watersheds, few runoff records were obtained. Of 31 storms, only 5 produced runoff of more than 0.01 inch. The average total runoff from the hillside plots was much higher than the runoff from the watershed. Much of the storm water was detained temporarily or absorbed en route to the weir. Part of the water was undoubtedly absorbed by the broad grassy swale in the valley (fig. 3, p. 5).

The infiltrometer studies yielded valuable information on factors affecting infiltration in this area, and the general hydrologic characteristics of the area.

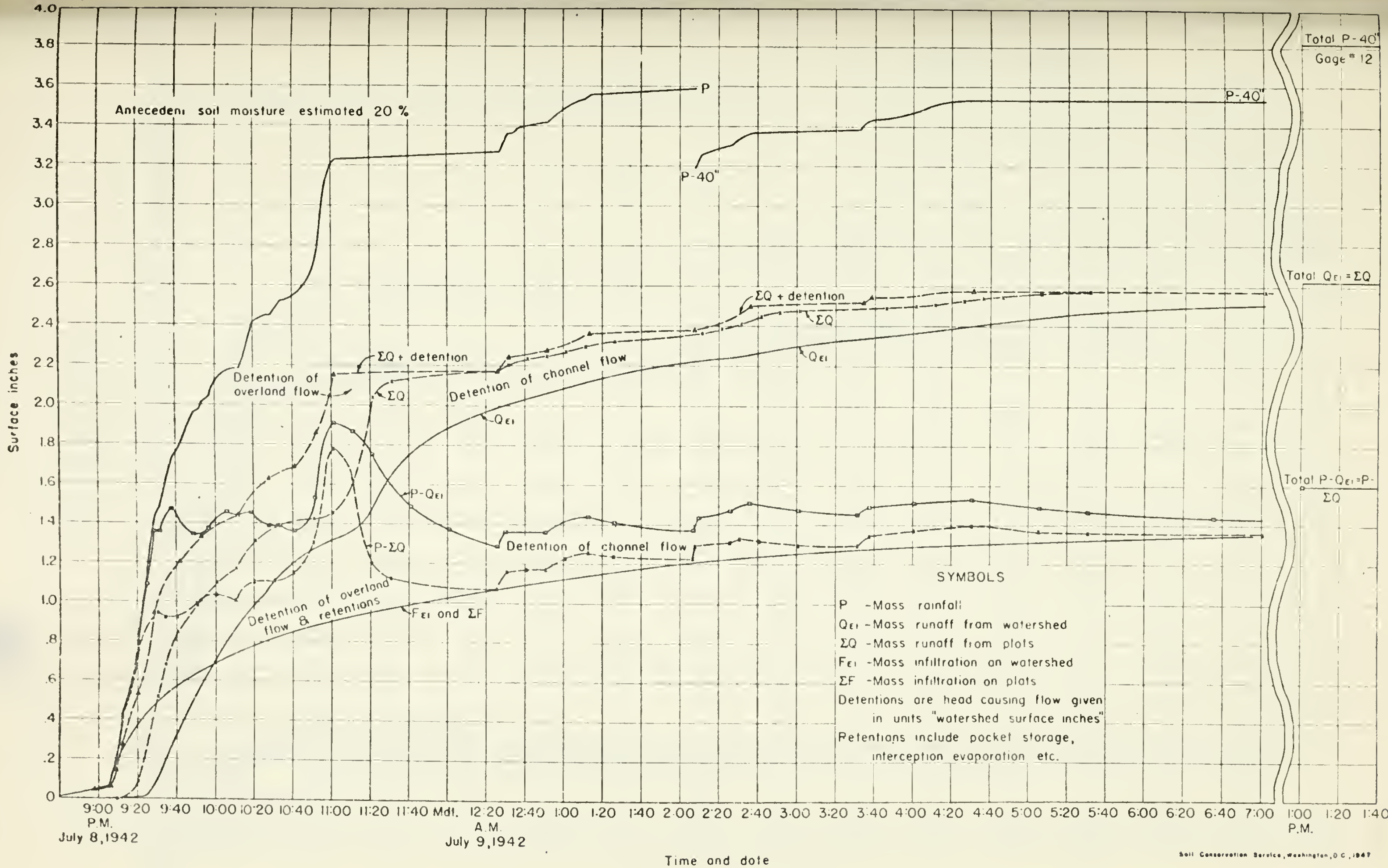


FIGURE 17.--Rainfall, runoff, and infiltration as indicated by plot averages and by watershed measurements for the storm of July 8 and 9, 1942, Watershed E-I, Edwardsville.

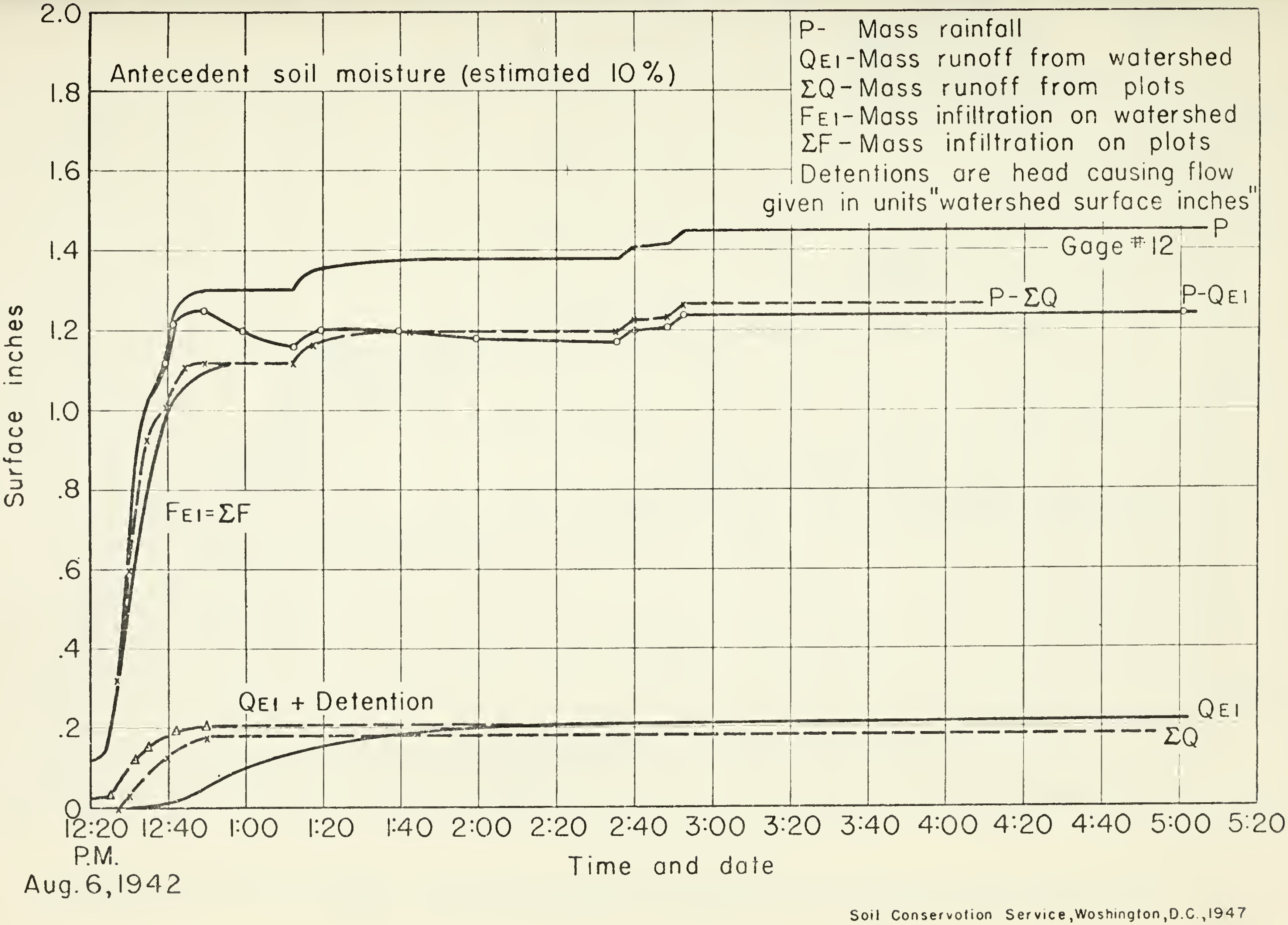


FIGURE 18.--Rainfall, runoff, and infiltration as indicated by plot averages and by watershed measurements for the storm of August 6, 1942, Watershed E-I, Edwardsville.

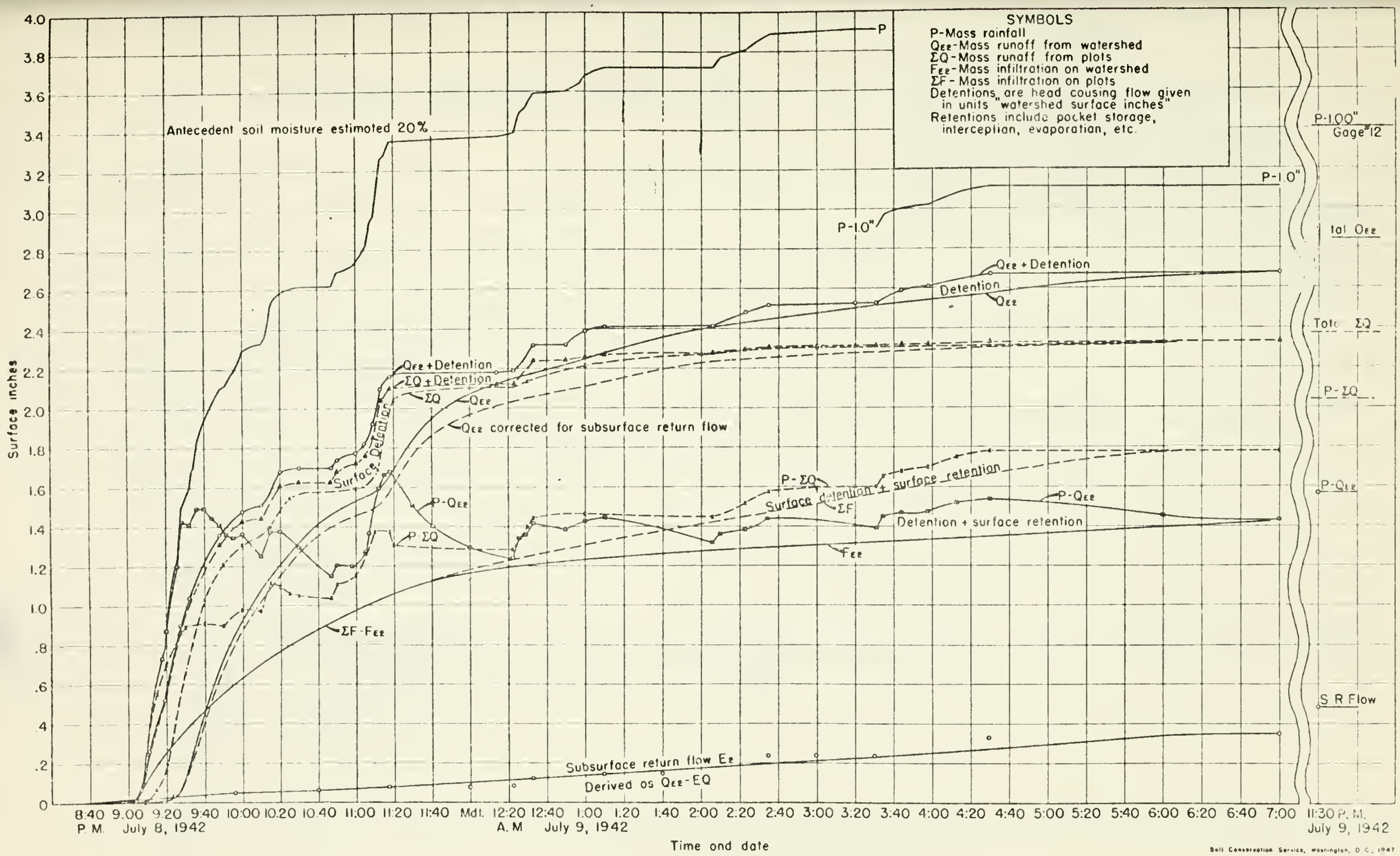
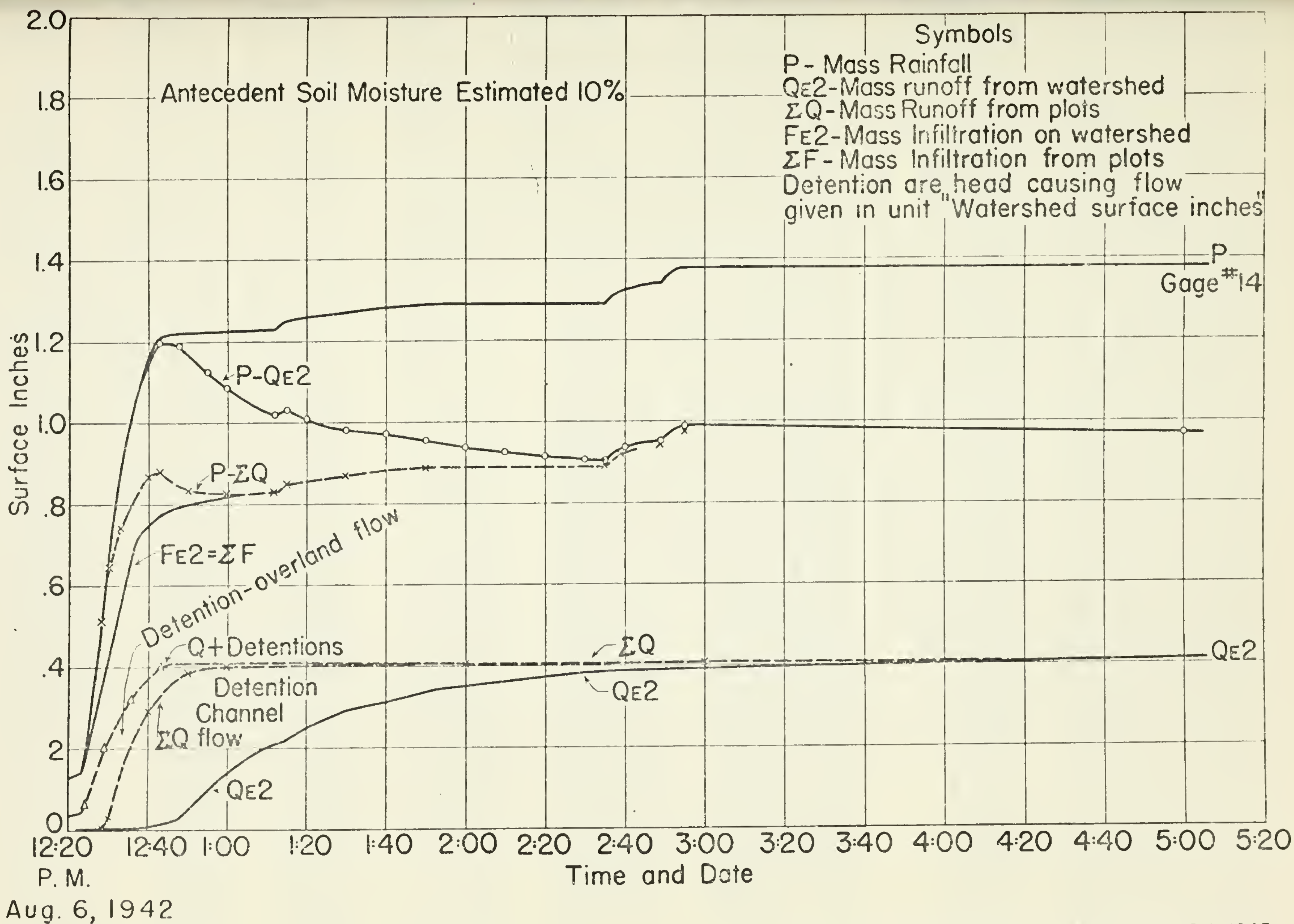


FIGURE 19.--Rainfall, runoff, and infiltration as indicated by plot averages and by watershed measurements for the storm of July 8 and 9, 1942.



Soil Conservation Service, Washington, D.C., 1947

FIGURE 20.--Storm of August 6, 1942, Watershed E-II, Edwardsville.

It was found, for example, that the kind and amount of native cover had a marked effect on infiltration. With a light stand of grama, weeds, and other plants that covered only 7 percent of the ground on hillside and sloping land, the final infiltration rate from late August to early October was only 0.227 inch per hour for the initial run. For the wet run it was 0.209 inch per hour. With a thick, rank cover of sand reedgrass covering 16.9 percent of the surface, but with soil and slope the same as for the lightly vegetated land, final infiltration rates were 1.65 and 1.03 inches per hour for initial and wet runs, respectively. This was slightly greater than infiltration where a good stand of blue grama (density 18.5 percent) grew on clay loam in the swale in the lower end of the watershed, despite the fact that the soil there was fairly deep and the land was nearly flat. On this area the final rates were 1.40 and 0.83 inches per hour for initial and wet runs, respectively.

Infiltration at Colorado Springs differed with the seasons. In the fall, infiltration slowed slightly from the late-summer rate; in the spring the rate increased markedly. In October and November, the same thinly vegetated plots studied a month or two earlier had an average final constant infiltration rate of 0.221 inch per hour; the more heavily grassed plots on the slope and in the valley had rates of 1.14 and 0.75 inches per hour, respectively.

Infiltration rates rise sharply in the spring (table 5, p. 34).

As indicated in table 5, the soil absorbed water much more quickly in the spring of 1942 than in the spring of 1941. This may have been due mainly to the fact that the growth of vegetative cover improved and the density of stand in general increased during the year. The results of all the infiltrometer runs for the Colorado area, when plotted against dates, confirm the fact that the infiltration rate rises to a peak in the spring of each year (fig. 21, p. 35). The frosts of winter probably loosen up the soil and help to increase the capacity of the soil to absorb water the following spring. In midsummer, baking of the soil and formation of dust on the surface undoubtedly account, in part, for low infiltration at that time of the year.

The rate of infiltration was not appreciably affected by the intensity of rainfall, other factors being the same. On a series of plots run in the winter of 1940-41, rainfall at intensities of approximately 1.7 and 3.4 inches per hour was applied alternately at intervals of approximately 40 minutes throughout the runs. Except for sharply reduced absorption in frozen soil, the average infiltration rate for all plots in the watershed differed only slightly for high and low rainfall intensities (table 6, p. 36).

The results of infiltrometer runs indicated that the soil moisture content prior to rainfall had no great effect on infiltration (table 7, p. 36). The data indicate that average wet-run rates were generally about the same as average initial-run rates. The few exceptions are explainable by abnormal conditions: either there was frost in the soil, or physical conditions commonly prevailing in the spring favored rapid infiltration.

Infiltration in this area reached in a short time a minimum constant rate which was then maintained for the duration of the run. The results of long and repeated runs on several plots (table 8, p. 37) show that there is no tendency for infiltration rates to decline, at least not for 150 minutes. It is probable that if the conditions prevailing on these plots had remained unchanged, water would have been absorbed indefinitely at the approximate rate shown in table 8.

The rate of infiltration tends to maintain itself through prolonged storm periods, but fluctuates with changes in temperature (fig. 22, p. 38). A 50-hour run was made to determine the influence of temperature. During this run there was no apparent tendency for infiltration rates to decrease, other than that due to temperature changes. Infiltration rates and temperatures each hour during this run proved to be highly significantly correlated.

Almost invariably, the infiltration rate for the sloping lands with Bresser clay loam and light cover was high at the start of rainfall, then slowed rapidly during the first 10 minutes. During the next 10 minutes the rate slowed much less rapidly, and generally infiltration reached a minimum constant rate at 30 minutes. Thereafter, rates remained practically constant, or even rose slightly in several instances. On the Nunn clay loam in the valley, and on Bresser clay loam with

TABLE 5.--*Final constant infiltration rates of four plots during nine separate periods, 1940-1942, Colorado Springs, Colo.*

Plot No.	Aug. - Oct. 1940		Oct. - Nov. 1940	Apr. - May 1941	May - June 1941	June - July 1941	July - Aug. 1941	Sept. - Oct. 1941	Oct. - Nov. 1941	Apr. - May 1942
	I.[1]	W.[2]	I.	I.	I.	I.	I.	I.	I.	I.
					Inches per hour.					
6	0.19	0.19	0.18	0.69	0.27	0.26	0.31	0.36	0.37	1.00
11	.20	.20	.22	.38	.35	.33	.41	.39	.41	1.20
12	.25	.18	.24	.38	.32	.27	.31	.21	.22	1.12
15	.21	.21	.24	.96	.22	.36	.36	.36	.22	1.38
Average	.21	.20	.22	.60	.29	.30	.35	.33	.30	1.18

[1] I - signifies initial or first run at prevailing field moisture.

[2] W - signifies wet run, following initial run usually by 24 hours.

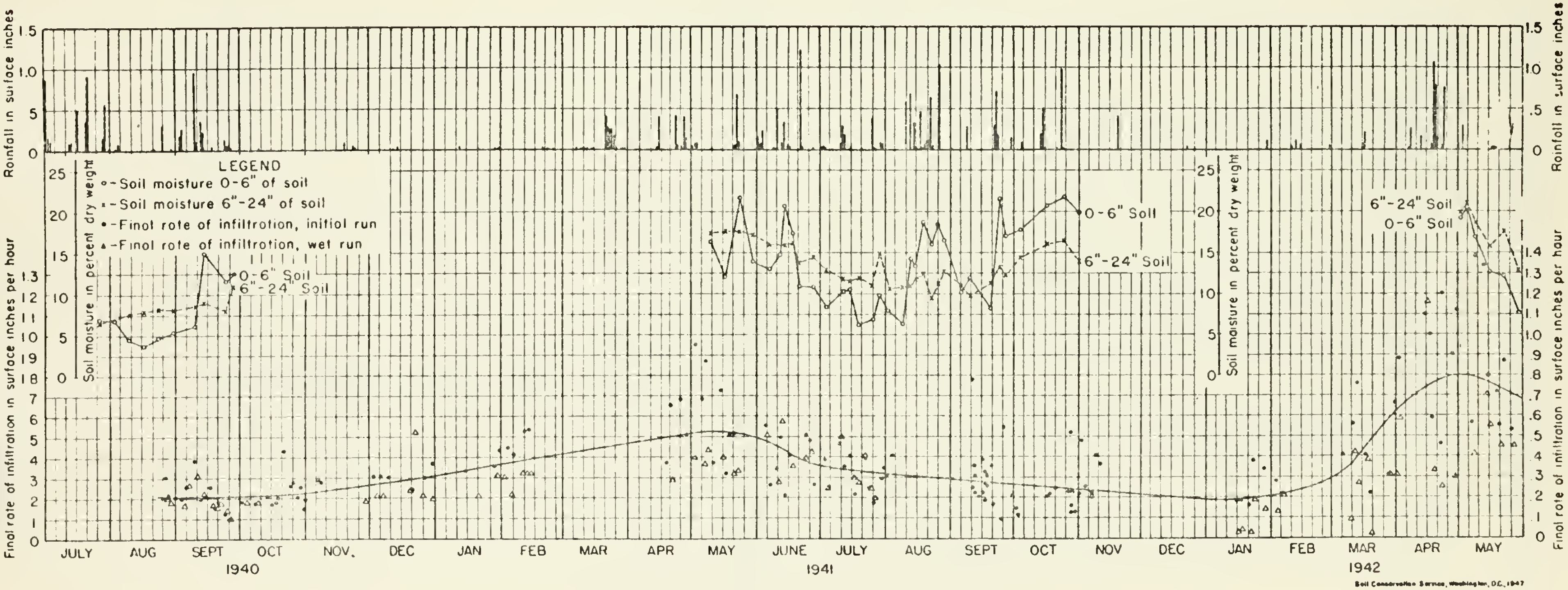


FIGURE 21.--Seasonal variation in rainfall, soil moisture, and final rates of infiltration as determined by the ''F'' unit infiltrometer, Colorado Springs.

TABLE 6.--*Terminal infiltration rates at alternating high and low rainfall intensities on 15 F plots, Colorado Springs, Colo.*

Plot No.	Rainfall intensity				
	High	Low	High	Low	High
	In./hr.	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*
1	0.47	0.24	0.19	0.18	0.19
2	.24	.32	.30	.31	.39
3	.40	.52	.62	.63	.66
4	.21	.25	.22	.30	.21
5	[1] .07	.21	.28	.35	.37
6	.35	.31	.29	.32	.30
7	.21	.22	.20	.21	.21
8	.21	.19	.20	.28	.26
9	.37	.32	.30	.31	.32
10	.25	.21	.17	.22	.18
11	.35	.32	.35	.34	.36
12	.20	.21	.21	.24	.22
13	[1] .08	[1] .06	[1] .01	[1] .05	[1] .06
14	.25	.20	.18	.21	.19
15	.27	.30	.27	.31	.28
Averages	.26	.26	.25	.28	.27

[1]Soil frozen.

TABLE 7.--*Terminal infiltration rates of F plots on Bresser (hillside) soil with light cover in watershed CS-III, Colorado Springs, Colo., Aug. - Oct. 1940*

Area No.	Initial run	Wet run
	In./hr.	*In./hr.*
1	0.27	0.23
2	.16	.18
3	.20	.19
4	.11	.11
5	.	.
6	.19	.19
7	.14	.15
8	.31	.31
9		
10	.22	.20
11	.20	.20
12	.25	.18
13	.44	.33
14	.25	.23
15	.21	.21
Averages	.23	.21

TABLE 8.--*Average infiltration rates for consecutive 30-minute periods of an initial and three wet runs, type F infiltrometer, Colorado Springs, Colo.*

Type run	30 - 60 minutes	60 - 90 minutes	90 - 120 minutes	120 - 150 minutes
	In./hr.	*In./hr.*	*In./hr.*	*In./hr.*
Initial, 1st day	0.33	0.32	0.31	0.32
1st wet, 2d day	.28	.30	.32	.35
2d wet, 3d day	.32	.31	.32	.34
3d wet, 4th day	.28	.31	.30	.33

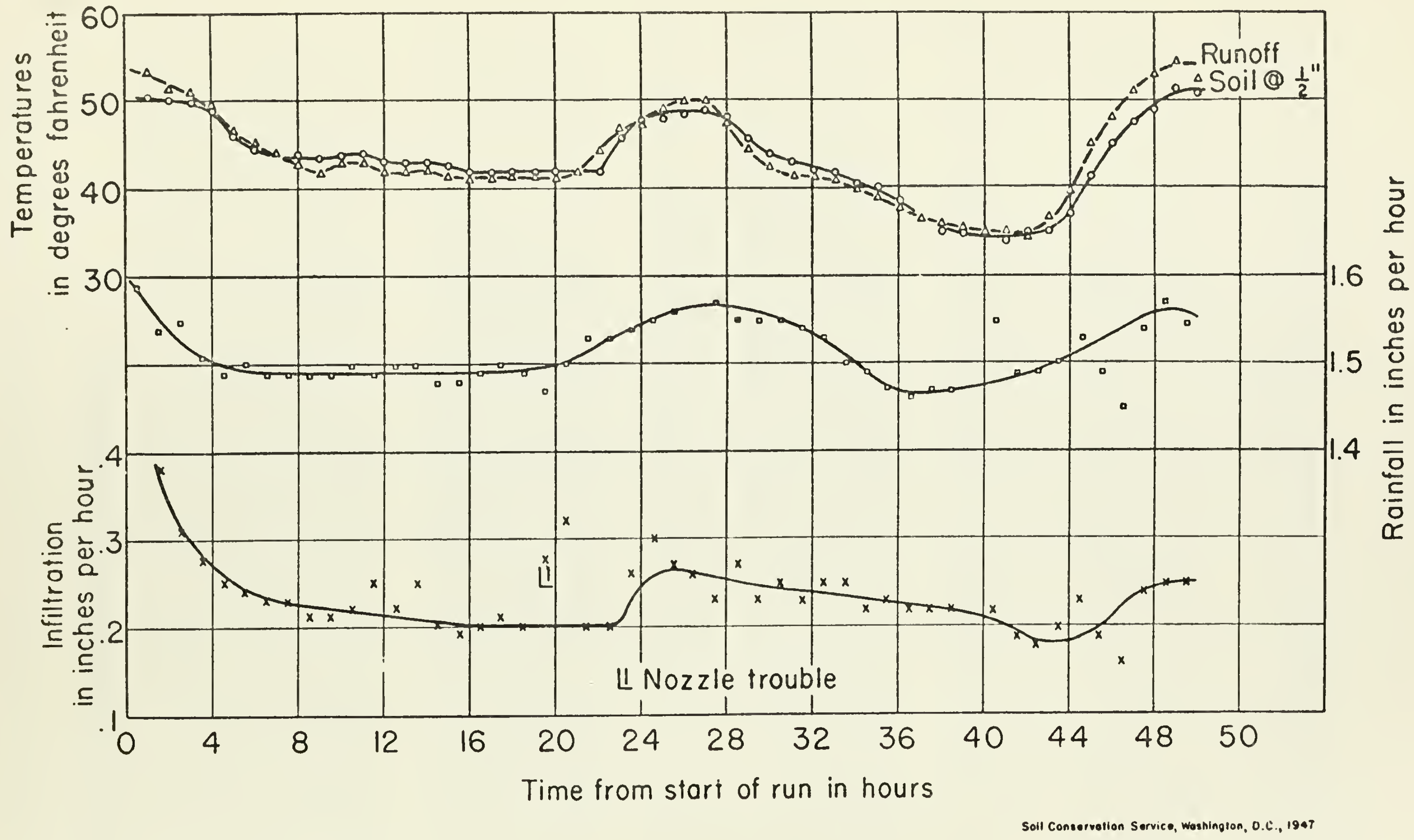


FIGURE 22.--Temperature, rainfall, and infiltration rates during a 50-hour run with the type ''F'' infiltrometer, Colorado Springs.

dense stands of sand reedgrass, rate of absorption was entirely different. It slowed down more gradually.

<u>Using Infiltration Studies in the Design of Runoff Control Measures</u>

The designing of measures for the control of surface runoff, such as terrace systems, contour furrows and structures, always requires that estimates be made of the quantities of water and the peak rates of discharge that may reasonably be expected under various specific conditions. Such estimates are essential to assure that sufficient capacities will be provided for control structures at a minimum of cost. Estimates are necessary regardless of whether the runoff results from frequent storms on farm fields or from infrequent flood-producing storms on large watersheds. Estimates based solely upon the characteristics of individual storms, however, are nearly valueless. By means of a simple graphic presentation of the rainfall and runoff for numerous storms (fig. 14, p. 22), it has been shown that there is no consistent relationship between these quantities. The defects inherent in such a comparison have become increasingly evident through numerous studies conducted in recent years.

Rainfall or storm characteristics are not satisfactory guides for the determination of runoff without additional information. In addition to reliable rainfall data for different parts of a watershed, information is particularly needed on the following items: (1) Infiltration characteristics of the various watershed segments, including a knowledge of how soil depth, soil moisture, plant cover, land use, and seasonal changes in physical conditions affect infiltration; (2) the drainage type and pattern, including the probability of channel storage or other lag in the movement of excess rainfall to the watershed outlet; (3) enough basic information to permit routing the excess precipitation from the different segments of the watershed to its outlet.

Much of the required basic information on the size, configuration, and vegetal cover of the watershed, and the general nature of the soil, is usually available. Other needed information, not so readily available, includes data on soil permeability and curves of infiltration rates.

The studies reported herein suggest how the information needed for good hydraulic and hydrologic design on agricultural and other lands may be obtained and applied. They show that in using rainfall and infiltration for determining watershed runoff it is usually not satisfactory to base the estimates on rainfall and infiltration for the watershed as a unit. It is probably better even in the absence of specific information on physical watershed conditions, to break up the watershed into segments and estimate the rainfall, infiltration, and runoff for each segment separately. In this way, errors tend to cancel one another and a more accurate result obtained.

All the watersheds studied were relatively small and uniform with a plant cover of either grass or alfalfa. The areas of each were small enough that a single storm tended to affect all parts of the watershed alike. It is reasonable to suppose that under these conditions internal variations are less important than on many large watersheds where physical conditions have a wider variation.

On the Edwardsville watersheds rainfall minus infiltration and surface retention, summed and weighted for the isopotal areas, was fairly indicative of the amount of runoff. However, this quantity of water is subject to temporary storage in the incised drainageways of these watersheds. Also the excess rainfall on the various isopotal areas is subject to other modifications while en route down the watershed. Therefore a simple subtraction of infiltration from rainfall would not give precisely the quantities or peak rates of discharge that are recorded for the watershed.

However, a proper allowance for surface detention, channel storage, etc., and routing of flood flows to the watershed outlet provides the basis for a close estimate of the watershed hydrograph. This is particularly true of the larger storms. For small storms the amount of water required to wet the surfaces of ground and vegetation is a relatively much greater part of the entire flow. These and similar discrepancies prevented a close agreement between computed and observed runoffs for small storms.